THE UNIVERSITY OF ALBERTA

PHYSIOLOGICAL CHARACTERISTICS OF COMPETITIVE MALE TRIATHLETES AND SPORT SPECIFIC TRAINING INTENSITIES

by

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A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE

OF MASTER OF SCIENCE

DEPARTMENT OF PHYSICAL EDUCATION AND SPORT STUDIES

EDMONTON, ALBERTA
SPRING, 1989

ISBN 0-315-53016-2

UNIVERSITY OF ALBERTA

RELEASE FORM

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TITLE OF THESIS: PHYSIOLOGICAL CHARACTERISTICS OF COMPETITIVE MALE TRIATHLETES AND SPORT SPECIFIC TRAINING INTENSITIES

DEGREE: MASTER OF SCIENCE

YEAR THIS DEGREE GRANTED: 1989

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UNIVERSITY OF ALBERTA

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Date April 26, 1989

ABSTRACT

The triathlon, a three sport event of swimming, bicycling, running is gaining considerable popularity. Many athletes competing in these races come from single sport backgrounds. Learning the new sports and training for three rather than one sport is very challenging. As an endurance event, triathloning requires optimal development of an athlete's maximal oxygen uptake and ventilatory threshold. Triathletes manipulate training variables based upon guidelines established for the single sports of swimming, cycling, and running. Exercise intensity is regarded as the most important factor in achieving the beneficial effects of training. Since little scientific data has been generated regarding training for triathlons, many common questions posed by these athletes remain unanswered. Guidelines specific to the triathlete do not exist, thus the purpose of this thesis was to physiologically characterize competitive male triathletes and investigate the hypothesis that differences may exist in training utilizing ratings of perceived exertion and heart rate monitors in swimming, cycling, and running. By determining the triathlete's rating of perceived exertion (RPE) and heart rate at ventilatory threshold for each sport in a laboratory setting and comparing it to the intensity at which training occured utilizing rating of perceived exertion and heart rate monitor, identified discrepancies allowed for a training error/efficiency rating to be calculated. The experimental group was comprised of twelve subjects who were competitve male triathletes. Statistical analysis justified the following conclusions: individuals experienced in a particular sport were able to correctly utilize the RPE and heart rate to monitor training intensity. However, in each sport the latter task is difficult thus, all triathletes can improve their training by utilizing the

heart rates at or just below ventilatory threshold with the aid of heart rate monitors.

ACKNOWLEDGEMENT

I would like to extend my gratitude to my Advisor and friend, Dr. Daniel Syrotuik who continually revived me and kept me laughing with his endless supply of wit and energy. Without his constant advise and attention I'm sure I'd still be collecting data.

My sincere thanks and appreciation are extended to my commitee members Dr. Art Quinney and Dr. Yagish Bhambani for their time and advise.

I would also like to thank my research assistants Patrick Neary, Ken Ross, and Kelly Yurasek.

Lastly, I extend my love and gratitude to my family who has endured my eight and a half years of education and my fiance Kipling Hladky who helped with my data collection and provided me with a smiling face at the end of many long days.

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CHAPTER 1

INTRODUCTION

The triathlon is a competition usually combining swimming, cycling, and running in succession over varying distances The most popular races are the Ironman consisting of 3.9 km. swim, 180.2 km. cycle, and 42.2 km. running and the USTS (United States Triathlon Series) triathlon which consists of a 1.5 km. swim, 40 km. cycle and a 10 km. run. This thesis will deal with triathletes competing in the latter category of races.

Triathletes come from single sport as well as multiple sport backgrounds. Training for three rather than one sport and learning the new sports is very challenging. Triathletes have many questions regarding the required training. For example, how long, how far, and at what intensity does training have to occur in each sport ? It was this researcher's objective to find some of the answers to these common questions based upon knowledge obtained from physiological and practical research dealing with triathletes.

It has been strongly suggested that intensity is the key variable affecting training success (Burke & Franks, 1975; Crews & Roberts, 1976; Davies & Knibbs, 1971; Faria, 1975; Sharkey, 1970; Wenger & MacNab, 1975). Researchers suggest training at an intensity at or just below the ventilatory threshold (Gibbons et al., 1983; Golden & Vaccaro, 1986; MacDougal & Sale, 1981). In order to prescribe this training intensity it is necessary to measure in a laboratory setting, the individual's ventilatory threshold and corresponding heart rate. Training is then prescibed based upon the heart rate obtained at the ventilatory threshold. Merely prescribing a heart rate at which to train may not be adequate. The need for more precise control of training intensity is necessary. Such control may come from the use of ratings of perceived exertion or a heart rate monitor. It is the researcher's objective to determine which of these devices will be best utilized by the triathlete.

A. Purpose

The purpose of this study was two-fold. The first aim was to develop physiological profiles of male triathletes. The second aim to investigate the hypothesis that differences may exist in training utilizing ratings of perceived exertion and heart rate monitors in swimming, cycling, and running.

B. Limitations

1) variations and effects of air temperature, humidity, and water temperature during laboratory and field measurements could not be precisely controlled.
2) the reliability and limitations of the specific testing procedures were not experimentally established.
3) motivation during training measurements and subsequent effects on heart rate could not be controlled.
4) a response for an RPE value for a given individual was approximate to the extent of intra-individual variation and experimental error.

5) the subjects training and living habits could not be controlled.

C. Delimitations

The study was delimited to 12 healthy male triathletes ages 20 to 28.

D. Justification

With the widespread growth and popularity of triathlons and the lack of scientific research data, this study will provide a source of information from which direction and understanding of various physiological and training recommendations can be drawn. The accumulation of data on specific training intensities provides a tool for training guidance for present and future triathletes.

E. Definitions of Terms

Anaerobic threshold - the exercise intensity above which plasma lactate rises and ventilation increases disproportionately to the oxygen uptake (Wasserman & McIlroy, 1964; Wasserman et al., 1967; MacDougall, 1977).

Competitive - connotes regional individual or team sport experience.

Cycling field test - measurement of training heart rate while cycling on bicycles mounted to windtrainers or rollers for a duration of 45 minutes.

Elite- connotes international or national sport experience.

Heart rate at rating of perceived exertion (HR @ RPE)- the mean heart rate obtained from rating of perceived exertion training sessions in swimming, cycling, and running.

Heart rate at heart rate monitor training sessions(HR @ HR/MON)- the mean heart rate obtained from heart rate monitor training sessions in swimming, cycling, and running.

Heart rate at ventilatory threshold (HR @ VT) - the heart rate measured at the time considered to be at or slightly below ventilatory threshold.

Heart rate monitor training sessions (HR/MON) - the use of a specific heart rate obtained from laboratory testing and used to prescribe training intensity during field testing in swimming, cycling, and running.

Maximum oxygen uptake (VO_2 max) - the point at which increased workloads did not elicit any further changes in oxygen consumption (Broudha, 1962; Cumming & Dazzinger, 1963; Hill & Lupton, 1923). Indicated by: a plateau with less than a 100 ml increase in VO_2 (Dwyer & Bybee, 1983; Ready & Quinney, 1982; Thoden et al., 1983); a leveling off and then a decrease in VO_2 (Ready & Quinney, 1982) or voluntary termination of the test. Peak oxygen uptake was the highest value of oxygen uptake where a plateau did not occur.

Optimal training success - the ability to perform an increased physical task during a certain period of time at the same energy cost which implies a better sport performance.

Pre-determined comfort speed - a speed (mph) which was determined in previous testing to be comfortable for the subject.

Ranking - values were ranked highest to lowest from 1 - 12 or 1 - 3.

Rating of perceived exertion (RPE)- an indicator, based upon a scale from 6-20, of the degree of physical strain exerted by the body while performing work (Borg, 1982).

Rating of perceived exertion (RPE) training sessions (RPE @ VT) - an RPE associated with each individuals ventilatory threshold obtained from laboratory testing and used to prescribe training intensity during field testing in swimming, cycling, and running.

Significant sport experience (SSE) - the single sport identified by each subject as that which was experienced in childhood or adulthood to the greatest extent.

Significant sport ranking (SSR) - the sports, ranked by the subjects, as ranging from their best to their weakest as well as those to which they contribute the greatest amount of training.

Sport tester heart rate monitor - an instrument consisting of a pulse transmitter attached to an electrode belt, worn around the chest at the level of the fifth intercostal, and a microcomputer watch-like receiver, worn on the wrist. The Sport-tester can monitor and store heart rate responses every 5 seconds for up to 64 minutes.

Swimming field test - measurement of training heart rate while swimming for a duration of 45 minutes in an indoor swimming pool.

Training heart rate - the maintenance of a steady heart rate within +/- 5 bpm for 40 minutes based upon previously identified RPE and measures of heart rate at ventilatory threshold.

Triathlete - an individual who participates in races consisting of consecutive swimming, cycling, and running.

Triathlete experience (TE)- the number of years in which the individual had been training in all three sports.

Ventilatory threshold - the exercise intensity above which ventilation increases disproportionately to the oxygen uptake (Wasserman & McIlroy, 1964; Wasserman et al., 1967). The primary criteria for identification of this point was a nonlinear increase in Ve vs VO_2. Where use of secondary criteria was the point at which $FECO_2$ reached a maximum was used (Caiozzo et al., 1982; Davis et al., 1976; Green et al., 1983; Koyal et al , 1976; Wasserman et al., 1973).

CHAPTER II

REVIEW OF LITERATURE

A. Physiological Requirements of Triathlons

The ability to be successful or to win at competitive sports is dependent upon numerous, unalterable factors, some of which include age, sex, height, and genetic endowment, and alterable factors such as motivation, training status, and environmental variables. According to Smith and Kempire (1984), repeated physical exercise can produce beneficial training effects that alter the body's ability to perform work for a prolonged period of time. Since the purpose of training is to induce adaptations for improved performance, the demands of the event need to be matched by the individual's capabilities so that top performance can be achieved. It is the job of the exercise physiologist to analyze the requirements of the sport and to aid coaches in their task of selection, preparation, and improvement of athletes.

A.1. TRAINING INTENSITY PRESCRIPTION

Muscles are dependant upon the supply of energy furnished either anaerobically or aerobically. Since anaerobic stores of energy are limited, prolonged muscular work ultimately depends upon the body's ability to consume, transport and utilize oxygen. Oxygen uptake (VO_2), usually expressed as litres of oxygen per minute, is regarded by Wenger and MacNab (1975) as a reliable measure of muscular activity and a powerful predictor of endurance performance.

The physiological requirements for the performance of work involve a functional coupling of accelerated cardiovascular and respiratory activity to achieve the exchange of oxygen and carbon dioxide between the muscle cells and the atmosphere in response to the increased metabolic stress (Wasserman & Whipp, 1975).

The latter responses are so precisely geared to the rate at which performance is occurring that oxygen consumption increases in a true linear fashion in response to the workload. Research findings have indicated there is a point at which increased workloads will not elicit any further changes in oxygen consumption (Cumming & Dazzinger, 1963; Broudha, 1962; Hill & Lupton, 1923). This point is referred to as maximal oxygen uptake (VO_2 max) or the maximum aerobic power of an individual. Often it is indicated by: 1) a plateau in oxygen uptake values within a specific range i.e. 80-150 mls (Astrand, 1960; Thoden et al., 1983), 2) the leveling off and then a decrease in oxygen uptake (Ready & Quinney, 1982), or 3) peak oxygen uptake where due to exhaustion the individual could no longer perform work (Thoden et al.,1983).

VO_2 max is specific to both the individual (Hill & Lupton, 1923), the form of exercise, and the mass and type of muscle involved (Broudha, 1962; Smith & Kempire, 1984; Tanaka, 1984).

The effects of training on VO_2 max suggest increases ranging from 10-20% depending upon the individual's initial level of fitness, genetic endowment, (Davies & Knibbs, 1971; Hickson et al., 1977; Saltin & Astrand, 1967) and intensity, duration, and frequency of training (Astrand & Rhodahl, 1977; Beaker & Vaccaro, 1983; Ekblom, 1969; Fox et al., 1977; Gaesser et al.,1985; Henritze et al., 1985; Hickson et al., 1977; Pool & Gasser, 1985; Ready & Quinney, 1982; Tanaka et al., 1984).

The exact mechanisms which determine an individual's VO_2 max and it's trainability are uncertain but researchers believe a combination of factors may be responsible. These include:

1. an increase in the size and number of the mitochondria allowing for greater oxygen extraction from the blood (Fox et al., 1977; Gollnick et al., 1973; Hickson et al., 1977; Holloszy, 1973; Karlsson et al., 1969; Smith & Kempire, 1984).
2. increased oxygen delivery to the muscles (Smith & Kempire, 1984).
3. increased activity of mitochondrial enzymes allowing for increased oxidative capacity in both fast and slow twitch muscle fibers (Costill et al., 1976; Gollnick et al., 1973; Holloszy, 1973).

Rusko et al, (1978) suggest VO_2 max might be the most important determinant of performance when large muscles are used during short and long periods of time based upon a high correlation $r = 0.94$ found between VO_2 max and running performance over a wide range of distances.

Lately it has been suggested that a submaximal criterion might be superior to VO_2 max as a determinant of endurance performance (Sjodin & Jacobs, 1981; Tanaka et al., 1984). Studies have illustrated that individuals with similar VO_2 max values perform quite differently. The basis for the difference is believed to be the ability to sustain exercise at a higher percentage of maximal aerobic power without accumulating fatiguing metabolities (Thoden et al., 1983; Weltman et al., 1978; Sjodin et al., 1982). Researchers refer to this phenomenon as the anaerobic (lactate) threshold.

Farrell et al, (1979) showed that of the various indices proported to predict endurance performance (running economy, relative body fat, VO_2 max, percentage of slow twitch muscle fibers, and the anaerobic threshold{LT}), a treadmill velocity corresponding to the anaerobic threshold yielded the highest correlation (r= 0.94) with marathon running performance.

Powers et al, (1983), using nine runners, showed that the anaerobic threshold (LT) correlated highly (r = 0.94) with 10- kilometer (km) race times.

Kumagai et al, (1982) compared 5 and 10 km times to the weight-correctedanaerobic threshold (LT) and VO_2 max in 17 runners. They found correlations of r = -0.95 and -0.84, for race pace versus the anaerobic threshold and r = -0.65 and -0.68 for race pace versus VO_2 max.

The original use of the anaerobic threshold was to describe the metabolic events such as increased carbon dioxide production and ventilation volume associated with the production of lactic acid during progressive exercise.

The term 'anaerobic' was important in the early application of the phenomenon based upon the belief that during severe forms of exercise, oxygen requirements could exceed oxygen availabilty resulting in the need for energy supplied from anaerobic metabolism and subsequent production of lactic acid (Hill & Lupton., 1923; Wasserman & McIlroy, 1964). Many studies to date have altered oxygen flow to the working muscles above a specific work rate in order to study the affected blood and/or muscle lactate levels

An increase in blood lactate has been observed as a result of:

1. decreased FiO_2 (Lundin & Strom, 1947; Hughes et al., 1968; Linnarson et al., 1974).
2. acute isovolemic anemia (Neil et al., 1969; Woodson et al.,

1978).

3. a relative lack of oxygen (Davis, 1985).
4. a saturation of the tricarboxylic acid cycle as a result of decreased speed of enzymatic reactions (Buono et al., 1984; Erikson et al., 1985; Vago et al., 1987).
5. recruitment of fast-twitch muscle fibres during graded exercise resulting in ammonium accumulation favoring anaerobic glycolysis (Buono et al., 1984; Erikson et al., 1985).
6. reduced circulating blood volume (Christensen & Christensen, 1978; Fortney et al., 1982).

A decrease in blood lactate has been observed as a result of:

1. increased FiO_2 (Banister at al., 1970; Gautier et al., 1978; Hughes et al., 1968; Lundin & Strom, 1947; Welch, 1977).

It is possible to attribute rises in plasma lactate concentration to an increasing use of glycolytic metabolic pathways due to the progressive recruitment of glycolytic muscle fibers and it is also possible that changes occur in the balance between the various regulatory enzymes, leading to production of pyruvate at a faster rate than its oxidation by the citric acid cycle (Jones & Eshram, 1982).

Studies have confirmed the detection of the anaerobic threshold based upon both lactate and ventilatory criteria, some indicating a high correlation between a rise in ventilation and the onset of blood lactate (Caiozzo et al., 1982; Davis et al., 1976, 1979; Koyal et al., 1976; McLellan & Skinner, 1981; Wasserman et al., 1973). However, there is some strong evidence that these two points are not coincidental (Green et al., 1983; Hagburg et al., 1982; Neary et al., 1985).

For the purpose of this study, the ventilatory threshold based upon non-invasive detection methods will be utilized. The techniques to determine the ventilation threshold are well supported and validated in the literature (Caiozzo et al., 1982; Neary et al., 1985). The ventilatory threshold is based upon the belief that during exercise of increasing power, ventilation (Ve) increases linearly with oxygen uptake with a point at which the straight line gives away to a curve of increasing Ve with respect to VO_2 (Golden & Vaccaro, 1984; Issekutz et al., 1965; Skinner & McLellan, 1980; Wasserman et al., 1973). A line drawn through the initial points of this relationship permits the identification of a VO_2 at which Ve breaks away (Wasserman et al., 1973; Weltman & Katch, 1979). The increase in ventilation may be shown to be caused by a relative increase in $PaCO_2$ content in blood as a result of increased pyruvate to lactate transformation, possibly as a failure of lactate clearance (Brooks, 1985a & 1985b), and the necessity of it's buffering by the bicarbonate system. The buffering of lactate by the bicarbonate system and the excess of carbon dioxide can be further explained by Equations 1. and 2.

Equation 1.

$$\underset{\text{lactic acid}}{CH_3CHOHCOOH} + \underset{\text{sodium bicarbonate}}{NaHCO_3} \longrightarrow \underset{\text{sodium lactate}}{CH_3CHOHCOONa} + \underset{\text{carbonic acid}}{H_2CO_3}$$

Equation 2.

$$H^+ + HCO_3 \longrightarrow H_2CO_3 \longrightarrow CO_2 + H_2O$$

hydrogen acid, bicarbonate, carbonic, carbon dioxide, water

Other methods of detection include:1) a nonlinear increase in carbon dioxide output, 2) abrupt systematic increases in the respiratory exchange ratio, 3) systematic increases in the ventilatory equivalent for oxygen uptake without concomitant increases in the ventilatory equivalent for carbon dioxide output, 4) increases in FeO_2 which are analogous to increase in the ventilatory equivalent for oxygen, 5) the point at which maximum $FeCO_2$ is reached, and 5) and increase in end-tidal PO_2 with a constant end-tidal PCO_2 (Caiozzo et al., 1982; Davis et al., 1976, 1979; Koyal et al., 1976; Wasserman et al., 1967; Whipp et al., 1974).

Physical fitness affects the substrate utilization pattern by apparently causing the unfit subject to reach his ventilatory threshold earlier, thereby utilizing a greater proportion of energy from glycolysis to perform work than the fit subject (Hermanssen, 1967; Yoshida et al., 1982).

When glycolysis becomes the preferred source of energy the resulting lactic acidosis according to Davis (1985) can clearly affect performance.
Effects may include: increased creatine phosphate breakdown, increased carbohydrate utilization, decreased muscle ph and decreased lipolysis with the consequence of greater dependence on the limited supplies of glycogen (Boyd, 1974; Fredholm, 1971; Hjemdahl & Fredholm, 1977; Issekutz & Miller, 1962; Issekutz et al., 1975), and decrease calcium triggering of muscle contraction (Hultman & Sahlin, 1980). The increased carbohydrate utilization may result in

glycogen depletion which has been associated with exhaustion during prolonged exercise (Costill et al., 1973). Since a triathlete's aim is to go as fast as possible without feeling the fatigue effects, lactic acidosis must be limited. Based upon information obtained from the detection of the ventilatroy threshold, the athlete may manipulate training intensities to increase his threshold. This may result in limiting the effects of lactic acidosis.

B. EFFECTS OF TRAINING

Rogers et al, (1986) studied 21 male triathletes to determine some of their physiological characteristics. He found VO_2 max correlated significantly with performance times in triathlons r= -.060 thus the triathlete wishes to increase VO_2 max. The triathlete, as previously indicated should increase his ventilatory threshold to allow him to sustain a given intensity of exercise for a longer period of time and to perform at a higher percentage VO_2 max for a fixed period of time in all three sports. MacDougall and Sale (1981) have identified possible mechanisms for increases in the ventilatory threshold resulting from training. These include central adaptations such as increased weight and volume of the heart, increased blood volume, and increased stroke volume and cardiac output, resulting in improved distribution of blood flow to trained muscle and peripheral adaptations including increased cellular oxidative capacity, possible changes in muscle fibre recruitment such as increased activation of relatively more slow-twitch fibres (Ivy et al., 1980; Sjodin et al., 1982) or a delayed activation of fast twitch fibers (Gaesser et al., 1984), and delayed onset of blood lactate accumulation. In addition, Ready and Quinney, (1982) included other possible training mechanisms, such as, changes in the muscle ultrastructure (Gollnick & King, 1969), increased capilliarization (Anderson, 1975; Andersen & Henriksson, 1977), and changes in substrate utilization patterns (Hermanssen et al., 1967).

Since the purpose of training is to induce the latter adaptations for improved performance and to obtain optimal training success, triathletes manipulate training load based upon parameters of frequency, duration and volume, intensity, and type or specificity (Davis & Knibbs, 1971; Faria, 1970; Pollock et al., 1969; Sharkey, 1970; Wenger & MacNab, 1975).

Existing evidence indicates intensity of training is the key variable representing the training effect and increased performance times result from exercise at an intensity that is closest to ventilatory threshold (Burke & Franks, 1975; Crews & Roberts, 1976; Davis & Knibbs, 1971; Faria, 1975; Fox & Matthews, 1981; Heinritze et al., 1985; Mader, 1980; Nupp, 1970; Rolstein et al., 1986; Sharkey, 1970; Wenger & MacNab, 1975; Yoshida et al., 1982).

Training intensity prescription can be based on the relative percent concept. This involves the use of pre-training test data based upon measured or predicted maximal physiological values, such as, maximum heart rate or maximal oxygen uptake. A relative percentage of the value is then assigned as the training stimuli on an individual, that is, an entire group may be assigned to train at 80%. The assumption is then that all the individuals will exercise at, above or below the defined threshold in order to achieve the desired training effects. There are many examples of this in the literature (Hickson et al., 1977; Davis & Knibbs, 1971; Gollnick et al., 1973; Orlander et al., 1977).

Another form of intensity prescription is based on a group basis absolute heart rate or percentage of VO_2 max.

Both the former and latter methods would cause variable stresses in the individuals. For example, Dwyer and Bybee (1983) in a study of 20 normal healthy females concluded that an exercise intensity selected from the literature and applied to a homogeneous group of subjects may have limited usefulness in ensuring all subjects train at a desired level of metabolic stress. Pollock (1973) believes training programs based on percent VO_2 max or maximal heart rate provide multiple training stimuli among individuals. The assignment should be specific to the each individual and specific to each form of exercise as measured under true laboratory conditions.

Since competitive triathletes are concerned with implications of over-training, time-management, and obtaining optimal efficiency and maximal benefits from their training, there is a need for more specific indices of the intensities at which to train in each sport. A number of researchers (Davis & Convertino, 1975; Davis et al., 1979; Dwyer & Bybee, 1983; Katch et al.,1978; Wasserman et al.,1973) have concluded the best method for training prescription is to make individual assessment of the ventilatory threshold and heart rate before assigning training heart rates.

The triathlete performs in three modes or types of exercise. Although all are mainly aerobic in nature, each has specific demands on the muscle groups required to perform a variety of movement patterns. Whether the triathlete must train specifically in each sport or whether training in one mode can affect performance in the other modes remains unanswered. The literature on the training specificity for triathletes, although sparse, indicates faster triathletes train in all three sports. Zinkgraf (1985) concluded specificity in training is necessary to do well in a triathlon and all three sports must be represented in the training regimen. Kohrt and co-workers (1987) studied the VO_2 max of trained triathletes in each sport of the triathlon and compared them to typical profiles of untrained subjects. The results indicated triathletes experienced specific adaptations in each activity which was associated with reduced VO_2 max decrements between running and swimming, and between running and cycling.

C. Ratings of Perceived Exertion

Another form of intensity prescription is based on the rating of perceived exertion (RPE) which is used as an indicator of the degree of physical strain exerted by the body while performing work (Borg, 1982). The category scale, commonly referred to as the Borg Scale, was developed by Borg (1970) so that perceptual ratings increased linearly with heart rate and metabolic stress for exercise on a cycle ergometer (Skinner et al., 1973). Support for this relationship is provided in reports of moderately high correlations between RPE and physiological variables such as heart rate, ventilation, and oxygen uptake (Bar-Or et al., 1972; Borg, 1973; Noble et al., 1973; Skinner et al., 1969; Skinner et al., 1973). The overall perception of exertion represents an individual's integration of various physiological sensations (Pandolf & Noble, 1983). In 1971, Ekblom and Goldbarg became the first scientists to suggest that the perception of intensity during exercise was based on two factors: a local factor associated with feelings of strain in the exercising muscles and or joints, and a central factor associated with feelings from the cardiopulmunary system such as heart rate and ventilation rate. They further suggested the local factors seem to act as primary cues while the central factors appear to play more of a secondary role. Based upon these relationships, the scale is used to prescribe and control exercise intensity in laboratory, occupational and technical settings. According to Noble (1982), quantification of effort associated with sport activities allows optimal and reproducible pacing in training and competition.

Since the ventilatory threshold (VT) or lactate threshold (LT) has been proposed as a more accurate training index than absolute heart rate, percentage of heart rate maximum, or percentage of VO_2 max for the prescription of exercise training intensity (Brehm et al., 1985; Davis et al., 1979; Katch et al., 1978; Kindermann et al., 1979; Purvis & Cureton, 1981), researchers suggest RPE associated with the ventilatory or lactate threshold be used as a viable method of exercise intensity prescription (Purvis & Cureton, 1981; Smutok et al., 1980). Studies have reported mean RPE's between 12 and 14 at either the LT or VT in a variety of individuals, including moderately conditioned young men and women (Bellew et al., 1983; Purvis et al., 1981), and unconditioned middle-aged men (Dressendorfer et al., 1981). DeMello et al, (1987) studying trained and untrained males and females, found the mean RPE at LT to be 13.5 and 12.9, respectively for the untrained individuals, and 13.6 and 13.5, respectively corresponding to a perception of 'somewhat hard' for those who were trained. Simon et al, (1983), found the mean RPE at VT in untrained individuals to be 10.5 and trained individuals to be 13.5.

The linear relationship between heart rate and RPE have been indicated by some researchers, however these findings have been disputed. For example, Davies and Sargeant, (1979) and Ekblom and Goldbarg, (1971) manipulated the heart rate with the use of parasympathetic and sympathetic blocking agents without affecting the RPE at a given percentage of VO_2 max. Pandolf et al, (1978) found RPE to be greater for eccentric than concentric exercise at the same heart rate. In a number of studies involving varying climates, alterations in heart rate response as compared to RPE have been found (Kamon et al., 1974; Noble et al., 1973; Pandolf et al., 1972), although these findings have been disputed (Skinner et al., 1973b).

Training studies have indicated there are no changes in RPE associated with post training changes in heart rate. Lewis et al, (1980) following an 11 week training program showed reduced submaximal heart rates while RPE remand the same. Sidney and Shepard, (1977) in a 34 week conditioning study reported that while post training heart rate responses were reduced at an absolute workload, RPE remained unchanged.

Some studies have reported changes in RPE associated with training responses. For example, Michael & Hachett, (1972) and

Sidney & Shepard, (1977) have reported discrepancies in RPE response at a given heart rate on varying modes of exercise. Lewis et al, (1980), however, observed a significant reduction in RPE at a fixed workload following an 11 week training program conducted at 75 to 80% of VO_2 max. Following a three week, low intensity, long duration activity study, Pandolf et al, (1975) found RPE to be lower at a specific heart rate or VO_2. Other studies (Ekblom & Goldbarg, 1971; Knuttgen et al., 1982) have reported similar findings.

Although there is strong support for the use of RPE, as well as a sound basis for the use of RPE as detected at the VT or LT, any reliable application of effort ratings in the control of exercise intensity is dependent upon the individuals' abilities to reproduce similar levels of work at equivalent metabolic demands across a range of exercise intensities, on different occasions, and in the case of the triathlete, in different sports (Eston et al., 1987).

Little information exists regarding RPE use as compared to use of a heart rate monitor particularly at threshold values in different sports. Perhaps some athletes are able to depend upon the use of an RPE rating for training in a particular sport or part of the season, while others with less experience may need to depend upon heart rate monitoring.

D. Heart Rate Monitoring

The use of heart rate monitoring is widely used today and necessitates the monitoring of heart rate either by some mechanized device (ECG, pulse counter, Sport tester) or by the exercisers counting their own pulses. Errors however in determining heart rate have been shown to occur due to pulse counting errors (Slater-Hammel & Butler, 1940), palpation site (White, 1977) and from the time delay encountered during post-exercise pulse location (McArdle at al., 1969; Pollock et al., 1972). It is also possible for individuals to become preoccupied with pulse counting to the extent that performance can be negatively affected (Smutok et al., 1980). With the use of heart rate monitoring the effectiveness of training programs in relation to physical conditioning and over-training can be monitored (Nye, 1987). Thus in order to determine if training is taking place at appropriate intensities valid and reliable methods must be used. The Sport tester elicited correlations of r = .95 - .97 with ECG monitoring and are easy to use in each of swimming, cycling, and running (Leger & Thivierge, 1988).

E. Summary of Review of Literature

1) Optimal training success depends upon the triathletes ability to develop his maximal oxygen uptake and ventilatory threshold in all three sports.

2) Intensity of training is the key variable representing the training effect.

3) The optimal intensity of training is that which is closest to ventilatory threshold.

4) Measurement of ventilatory threshold and heart rate in each sport is necessary before assigning training heart rates.

5) The use of the rating of perceived exertion at ventilatory threshold in each sport may be an appropriate training stimulus if it corresponds to the heart rates at ventilatory threshold, in each sport.

6) A superior method may be the use of a sport tester heart rate monitor to ensure training is in fact taking place at the proper intensity, in each sport.

CHAPTER 111

METHODS AND PROCEDURES

A. Subjects

12 male triathletes between the ages of 20-28 who had competed in at least two USTS length triathlons and who were training at the time of the study with aims of further competition, volunteered for this study.

B. Physical Conditions of the Laboratory

The temperature of the lab was maintained at 21° C (70° F). The humidity was not controlled. The temperature of the swimming pool was maintained at 28° C (82° F) for all testing sessions.

C. Calibration of Equipment

Prior to any testing all laboratory instruments were calibrated as follows:

1. Treadmill

The treadmill was calibrated by measuring the distance of the belt, counting the number of revolutions for a given amount of time and a given distance. The percent grade was calculated by using a levelling device.

2. Bicycle

The flywheel was removed and the mark on the pendulum set at 'zero' kilopond (kp). A calibrated metal weight of one kilogram (kg) or 2.2 pounds (lb) was added to the end of the lever and the resulting deflection of the pendulum mark read '1 kp' from the scale. A second kg weight was added and the process continued to the end of the scale ('7 kp'). Adjustments were accomplished by adjusting a screw which altered the center of gravity of the sinus balance.

3. Swimming

Weight of the .25 (.55), .5 (1.1), and 1.0 kg (2.2 lb) to be used in the tethered swimming, were weighed on three different scales to ensure accuracy.

4. All tests

Metabolic Measurement Cart (MMC),(Beckman Instruments Inc.,Illinois), was calibrated before and after each test with known mixtures of gases to correct any instrument drift. Volume was calibrated with known volume of air prior to each testing session.

Hydrostatic weighing equipment was calibrated as follows:

1. Sargeant Recorder

   The recorder was zeroed at '0' and '90', at least three times.

2. Strain Gauge

   Weights of 9.2 kg (20.2 lb) were placed on the chair in the water and the Sargent Recorder was then zeroed again, three times.

Harpenden Skinfold Caliper was calibrated by zeroing the dials.

Sport tester heart rate monitors were compared to electrocardiogram (ECG) outputs on an exercising subject to ensure accuracy in heart rate recording. Reliability correlations ranged from r = .86 - .99 (unpubl.data).

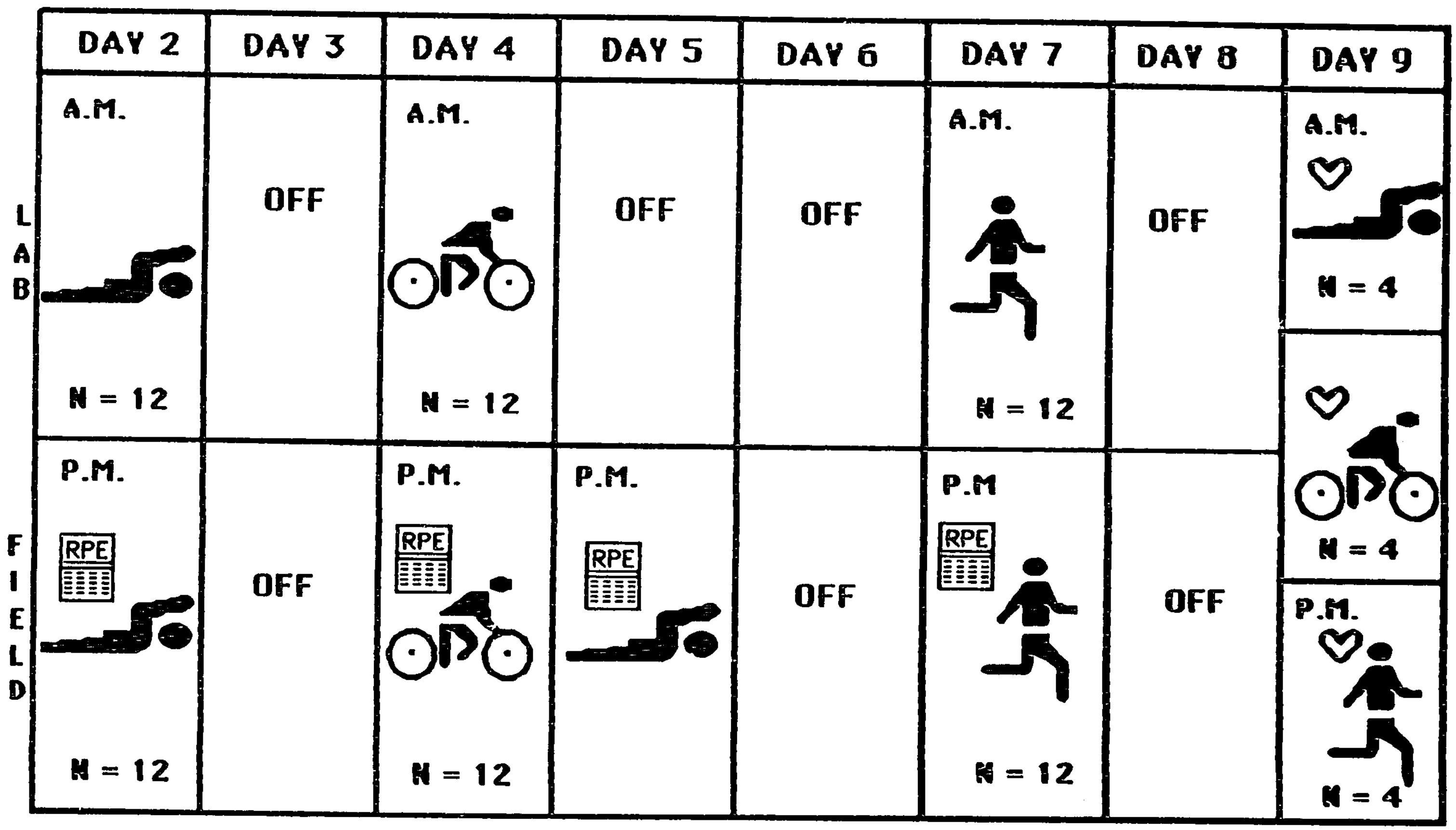
D. Collection and Analysis of Gases

Prior to each test, the MMC was programmed with the subjects' weight. A Hans-Rudolph non-rebreathing valve was connected to a lightweight plastic headpiece and fitted with a sterilized rubber mouthpiece. The subjects' nose was clamped with a rubber clip. A lightweight, flow-resistant, flexicoil, plastic hose was attached to the "out" vent of the valve and coupled to the MMC. Respiratory and metabolic measures including R, VE, VO_2, VCO_2, FEO_2, and $FECO_2$ were monitored every 30 seconds. Temperature, barometric pressure, cumulative time and time of each output were also recorded.

E. Testing Schedule

The testing schedule is presented in Figure 1. Day 1 began with an explanation of the testing schedule. Following written consent (Appendix A), identification of significant sport experience, significant sport ranking, and triathlon experience, and distribution of training diaries (Appendix B), test protocols were explained. Prior to data collection, all subjects were familiarized with all pertinent laboratory procedures by: 1) a 10 minute tethered swim with variations of weight in the bucket, 2) a cycle with variations in speed and resistance, and 3) a treadmill run with variations in speed and grade.

Based upon availability, subjects came to the physiology laboratories in the Department of Physical Education and Sport Studies at the University of Alberta to be tested on the bicycle ergometer and treadmill. All swimming tests took place in the East swimming pool. Field measurements for cycling and running took


DAY 2
DAY 3
DAY 4
DAY 5
DAY 6
DAY 7
DAY 8
DAY 9
LAB
FIELD
A.M.
N = 12
OFF
A.M.
N = 12
OFF
OFF
A.M.
N = 12
OFF
A.M.
N = 4
N = 4
P.M.
RPE
N = 12
OFF
P.M.
RPE
N = 12
P.M.
RPE
OFF
P.M
RPE
N = 12
OFF
P.M.
N = 4

place on the Rick Hansen Track in the Universiade Pavilion.

F. Pilot Study

Prior to the actual study, pilot work took place using a subject who did not participate in the present study. The pilot work involved testing the subject in each mode utilizing the protocols and criteria outlined in the present study. The pilot work allowed for the collection of pre-test data for the determination of the most suitable criteria and protocols to measure ventilatory threshold, maximum oxygen uptake, perceived exertion ratings, as well as heart rates in the field. Finally, it allowed the experimenter to become familiar with the methods and procedures of testing. Other previous pilot work involved testing seven of the present studies subjects utilizing the protocols and criteria outlined in this study.

G. Randomization

Subjects were not randomly assigned for laboratory measurements since the testing schedule did not allow for randomization of order. Subjects, however, were randomly assigned to one of three heart rating field testing groups.

H. Anthropometric Measures

1. Body Mass Procedure:

Subjects were weighed in bathing suits at the time of hydrostatic weighing on a calibrated beam balance Detecto Scale and recorded to the nearest 0.1 kg (.22 lb).

2. Height Procedure:

Measurement was taken as the maximum distance from the floor to the highest point on the skull when the subjects stood barefoot with heels together and arms hanging naturally by their sides. Heels, buttocks, upper part of back, back of head where in contact with the vertical wall. Subjects were instructed to look straight forward, with the body stretched upward to the fullest extent. A set square rested against the wall and on the top of the head. Subjects took a deep breath, moved away from the wall and the measure was marked and recorded.

3. Skinfold technique

The skinfold sites were located and marked. A double layer of skin and subcutaneous tissue was grasped firmly by the left thumb and index finger of the tester and was held throughout the measurement. Care was taken to ensure the caliper was applied at right angles to the fold at all times. Full spring constant pressure was applied to the skinfold and the reading taken.

The sequence of readings was repeated two times. If the two readings differed more than 0.4 millimetre (mm), a third reading was taken. The average of the two closest readings was accepted as the measure.

All of the following measures were taken on the right side of the body except for the abdominal fold, which was made on the left side.

tricep: a vertical fold raised on the posterior surface of the arm at a level midway between the tip of the acromion and the tip of the elbow.

bicep: a vertical fold raised on the anterior of the arm at a level midway between the acromion and the tip of the elbow as described for the tricep.

subscapular: measured one centimeter below the angle of the scapula in a direction running obliquely at an angle of about 45 degrees downwards from the spine.

supra-iliac: measured 3 centimetre (cm) above the iliac crest at the mid-axillary line with the fold running anterior and inferior.

supraspinale: measured about 7 cm. above the anterior superior iliac spine on a line to the anterior axillary border. The fold follows the natural fold lines running medial and inferior at about a 45 degree angle from horizontal.

abdominal: measured 5 cm. lateral to, and at the level of the amphalion.

front thigh: measured on the anterior of the mid-thigh along the long axis of the femur when the leg is flexed at a 90 degree angle at the knee. The mid-thigh is the estimated half-distance between the inguinal crease and the patella.

medial calf: a vertical fold on the medial calf at the estimated greatest circumference when the leg is flexed at an angle of 90 degrees at the knee.

4. Hydrostatic Weighing

Stainless steel cables were used to suspend an aluminum chair in the center of the tank. The cables were connected to a strain guage suspended from the ceiling. A Sargent Recorder was used to amplify and record the force acting upon the load cell of the strain gauge.

Since the weight underwater was recorded during maximum inhalation, a 9.2 kg (20.2 lb) weight was used to prevent floatation of the subject.

The subject, dressed in a swim suit was weighed on land on a Detecto scale to the nearest 0.1 kg (.22 lb).

The subject entered the tank and sat in the chair with the water level varying from shoulder to chin height.

Subjects were hydrostatically weighed at total lung capacity. Thus prior to weighing, the vital capacity of the subject was measured using a Collins Vitalometer. The subject was instructed to inspire maximally, pinch his nose closed with one hand, and exhale maximally. The largest volume of two trials was assumed to be the best estimate of vital capacity. Residual volume was estimated from the vital capacity.

The subject then placed the 9.2 kg (20.2 lb) belt of weights across his lap. Once comfortable the subject was instructed to lean forward until totally submerged in order to dislodge any air bubbles collected from the water and trapped on the skin and hair, and then return to an upright position.

The subject then inspired maximally, closed the nasal passage by holding his nose with one hand, and slowly leaned forward with as little movement of the chair as possible and without holding onto the chair, until his head was below the surface of the water.

The tester obtained the reading on the recorder and instructed the subject to lift his head. Five readings were taken with the lowest being recorded since the largest inhalation would cause the lowest reading.

The temperature of the water ranged from 31 - 36 ° C (88-97° F). Calculations of body fat are included in Appendix C.

I. Laboratory Testing

Essentially identical procedures were followed for the tethered swimming, cycle ergometry, and treadmill running. Subjects were requested not to ingest caffeine or exercise heavily three hours prior to testing. Subjects were asked to temporarily suspend their training for the duration of the study. T-shirts, shorts and regular training shoes were worn for cycling and the treadmill sessions and a swim suit for the tethered swim. All warm up periods were incorporated in each protocol. Once testing began, subjects were asked to indicate the rating of perceived exertion every minute and a half from the

Borg scale (6-20) as shown in Appendix D. If the threshold occured during the second minute, a mean of the two data points was used otherwise the first point corresponded to the first minute and the second point to the third minute. Verbal instructions and encouragement were given throughout the testing period. Each test period concluded with a five minute cool-down. Specific procedures were as follows:

I.1.Tethered Swimming Protocol

For the swimming protocol a water proof transmitter belt was worn and the monitor was held in the pool by a reseach assistant or by the subjects in their swim caps. A continuous three minute incremental tethered swimming protocol was used. The initial resistance was a 1.25 kg (2.75 lb) bucket with 1.25 kg (2.75 lb) increments every three minutes until the criteria for VO_2 max was achieved. In order for the above protocol to take place, it was necessary for the subjects to wear a belt around their waists which was attached to a bucket via a series of pulleys and ropes.

Subjects swam the front crawl stroke using the arms and legs in an unobstructed manner. They were instructed to keep their eyes fixed on a mark at the bottom of the pool to aid in maintaining a steady swim pace. For the collection of expired gases, the subjects breathed into a waterproof system consisting of a two-way valve attached to the Beckman analyzer and a coiled plastic tube extending above the water level to allow for the inspiration of air.

The RPE scale was sudivided (6-9; 10-13; 14-17; 18-20), attached to flutter boards, and waterproofed. At the beginning of the test, the first portion of the scale (6-9) was held underwater by a research asssistant. Once the last number on the board showing was identified, the next board was held under the water at the same time. This prevented limitations in the choice of numbers. This procedure was continued until testing was complete.

I.2 Bicycle Protocol

A Modified Monark Ergometer equipped with toe clips, adjustable racing seat and handle bars was utilized. Each subject adjusted the bicycle to their own comfort. The test began with the subject cycling at an established rate of 90 revolutions per minute (rpm). Cycling cadence was confirmed using microswitches and counter assembly. The test consisted of uninterupted three minute stages. The first stage began at 1.0 kp (90 watts). The second and third stages were increased by 0.5 kp (45 watts) and thereafter increments were .25 kp (22 watts). Near the end of the test, when subjects reported RPE values of greater than 18, .25 kp (22 watts) increments were added every minute until the criteria for VO_2 max were achieved.

I.3 Treadmill Protocol

Subjects commenced testing by running at 10 kilometers (km) per hour [6 miles per hour] at 0% grade for five minutes. The speed was then increased every three minutes by 1.6 km (1 mph) until the pre-determined comfort speed was reached for each subject. The grade was then increased 2 % every three minutes. Near the end of the test, when subjects reported RPE values of greater than 18, a 2% grade increment was added every minute until the criteria for VO_2 max were achieved.

J. Criteria for VO_2 max.

The criteria for determination of VO_2 max included: less than a 100 ml increase in VO_2 (Dwyer & Bybee, 1983); a leveling off and then a decrease in VO_2 (Ready & Quinney, 1982); or voluntary termination of the test (Thoden et al., 1982).

K. Criteria for Ventilatory Threshold

The criteria for determination of ventilation threshold was a nonlinear increase in Ve vs VO_2 (Golden & Vaccaro, 1984; Skinner & McLellan, 1980; Wasserman et al., 1973). Supporting criteria was the point at which $FECO_2$ reached a maximum (Issekutz et al., 1965; Smith et al., 1984). Based upon the above criteria, two independent evaluators determined ventilatory threshold.

L. Field-Measurement Procedures

Field measurements took place in the East pool, the physiology laboratory utilizing the subject's own windtrainers or rollers, and on the Rick Hansen Track.

A sport tester heart rate transmitter was attached by chest belts to the subjects and the monitors were worn around their wrists. The subjects were instructed to start the watches, use the first five minutes as a warm up and to then train uninterrupted for a total duration of 45 minutes (min). During the RPE @ VT training sessions, triathletes were instructed to train at the previously identified RPE @ VT. During the HR/MON training sessions, subjects were instructed to train at the previously identified HR @ VT. Post-analysis of one minute mean heart rates allowed for determination of the intensities at which the athletes were training. The criteria for training at the intensity of ventilatory threshold was the maintenance of the HR @ VT associated with each sport within plus or minus (+/-) five beats per minute (bpm).

M. Statistical Treatment

In order to prescribe sport specific training intensities, a specific heart rate within ± five bpm was given to each triathlete based on the discrepancy between the heart rate at ventilatory threshold as measured in the laboratory and heart rates at which aerobic work was performed based on the RPE or heart rate monitor feedback . The heart rate training sessions were utilized to indicate to the triathletes their capability of maintaining proper training intensity.

The following statistical analyses took place:

1. Descriptive analysis- means and standard deviation of age, height, weight, percent body fat, maximal oxygen uptake, ventilatory threshold, maximal heart rate are presented in tabular form.
2. Multiple correlation analysis was used to examine the relationship between the measured variables in each of the three modes of exercise (Appendix E).
3. One way analysis of variance was performed to evaluate the differences between VT and VO_2 max in each mode.

4. Simple regression analysis was used to determine the best predictor of HR @ VT from HR @ RPE and HR @ HR/MON.

In addition to statistical analysis there was a need for individual visual analysis of heart rate data since the representation of the mean data may have caused few differences to occur. For example, an individual may have been above and below his threshold at some point in the test, but the mean heart rate may not have indicated it, whereas visual inspection of the graphs allowed training errors to be indicated.

CHAPTER IV

RESULTS AND DISCUSSION

Physical Characteristics

A physical description of the subjects is given in Table 1. The mean age of the group was 24.8 ± 2.37 years with ages ranging from 20 to 28 years. The mean height of the group was 176.1 cm with a range from 166.5 to 182.0 cm.. Body weight ranged from 57.3 to 77.6 kg with a mean of 70.4 kg. Body fat obtained from hydrostatic weighing ranged from 8.6% to 17.7%, the mean value being 12.5% The measurements obtained from four skinfold sites, ranged from 8.4% - 18.2% with a mean value of 12.4.%. Total skinfold measurements ranged from 37.6 - 78.3 with a mean of 54.1.

Physical characteristics of triathletes and single-sport athletes are presented in Table 2.

The triathletes in this study were younger than most groups of triathletes previously examined (Kohrt et al., 1987; Holly et al., 1986; O'Toole et al., 1987; Rogers et al., 1986; van Rensburg.et al., 1984; Zinkgraf et al., 1986) and elite, competitive, and recreational runners (Costill, 1967; Foster et al., 1977; Housh et al., 1986; McArdle et al., 1978; Pollock, 1977) , but older than elite and recreational swimmers (Bonen, 1980; Gergley et al., 1984; Holmer et al., 1972 ; 1974), and competitive cyclists (Burke, 1980; Hagberg et al., 1979). Since the sport of triathloning is becoming very popular and there is increased growth in the USTS triathlons which require less experience and training, younger athletes are beginning to

TABLE 1. Anthropometric variables for 12 male triathletes

Subject No.	Age (yr)	Height (cm)	Weight (kg)	Bodyfat(%)		
					(Skinfold) 4 sites	(Hydro) 8 sites
1.	21	178	69.5	9.5	41.8	n/a
2.	23	173	70.8	18.2	47.1	17.7
3.	26	180.5	73.8	16.8	41.6	16.9
4.	22	180	76.5	15.1	36.0	15.0
5.	28	167	67.4	13.8	32.6	13.8
6.	27	179	77.6	8.4	20.7	9.0
7.	25	180	74.3	11.2	26.6	10.5
8.	22	182	71.3	10.5	25.0	12.8
9.	28	166.5	57.3	12.9	30.0	12.9
10.	26	173.8	70.5	10.8	25.6	8.6
11.	25	177.7	70.8	12.9	29.9	11.7
12.	25	176	64.5	9.4	22.8	9.1
Mean	24.8	176.1	70.3	12.4	54.1	12.5
±S.D	2.37	5.13	5.57	2.74	14.4	3.1
Range	21-28	166.5-182	56.8-77.6	8.4-18.2	37.6-78.3	8.6-17.7
S.E.	.7	1.5	1.6	.89	4.1	.95

TABLE 2. Physical characteristics of triathletes and single sport athletes (mean±SD,range).

Sport	Age(yr)	Height(cm)	Weight(kg)	Body Fat(%)	References
Triathletes					
	24.8±2.4 (21-28)	**176.1±5.1 (166.5-182)**	**70.3±5.6 (56.8-77.6)**	**12.5±3.1 (8.6-17.7)**	**present study**
	30.5±8.8 (20-50)	178.8±6.6 (168.9-190.5)	74.7±10.0 (68.2-94.1)	9.9±3.5 (4.9-15.2)	O'Toole et al, 1987
	31.7±7.9 (13-50)	179.7±6.45 (167.6-195.6)	74.4±8.0 (55.8-88.5)		Zinkgraf et al, 1986
	32.6±6.29	174.8±8.22	71.2±7.59 (47.6-93)		van Rensburg, 1984
	29.5±4.8 (23-35)		69.8±5.6 (60.3-78)		Kohrt et al, 1987
	29.1±1.6		77.2±1.8		Rogers et al, 1986
				(7.1-10.2)	Holly et al, 1986
	28.6±4.6	170.0±5.7	74.3±2.3		Kreider et al, 1988
Swimmers					
Elite/National					
	22	180	80		Holmer,I.,1972
	18.7	183.6	78.4		Holmer et al, 1974
	17.4	174.9	63.7		(series B) Bonen.et.al, 1980
	(12-32)	(158-180)	(45.6-72.2)		
	21.8	182.3	79.1	8.5	Wilmore & Bergfield, 1974
Recreational					
	22.8±2.0	178.4±1.5	76.7±2.9	33.5±.61	Gergley et al, 1984
	21.1±3.4	178.0±2.7	73.4±9.7		McArdle et al, 1978
Cyclists					
Competitive/Regional					
	>18	180.3		8.8	Burke,E, 1980
			(67.1-74.0)		
		182±3.6 (177.8-186.7)	73.4±4.95 (67.7-78.2)	8.8±2.4 (5.8-13.2)	Hagberg et al, 1979
Runners					
Elite/National					
	26.8				McArdle et al,.1981
		(176.4-179.3)	(62.6-65.7)	(3.4-8.0)	Pollock et al,.1977
Competitive/Regional					
	34.7±6.2	174.2±5	63.1±.4	7.85±1.9	Costill, 1973
	(25-48)	(165-182)	(50.3-73)	(4.7-11.3)	Foster et al, 1977
Recreational					
	33.8±3.6	177.7±.4	67.9±2.6	8.05±1.2	Housh et al,.1986

specialize in the three disciplines of triathloning, rather than remain involved in only one of the sports. This differs from earlier studies of triathletes involving individuals graduating to triathlons following college careers in one of the single sports and competing in Ironman triathlons which required a great amount of experience and training, thus the increased age of competitors (O'Toole et al., 1987).

When comparing the physique of triathletes in this study to that of elite swimmers, cyclists, and runners, the triathletes were found to be similar in height to the single-sport athletes as well as to other triathletes. The subjects weighed less than other triathletes (Kreider et al., 1988; O'Toole et al., 1987; Rogers et al., 1986; van Rensburg, 1984; Zinkgraf et al., 1986) and elite swimmers (Holmer et.al., 1974), but more than other elite swimmers (Bonen, 1980; Holmer, 1972), competitive cyclists (Burke, 1980; Hagberg et al., 1979) and elite, competitive and recreational runners (Costill, 1973; Foster et al., 1977; Housh et al., 1986; McArdle et al., 1978; Pollock et al, 1977). Because triathletes train in three sports it is expected that they are not as light as runners and cyclists, nor would they be lighter than elite swimmers who train a great deal.

Percent body fat obtained by both hydrostatic weighing and skinfold measurements were compared with other triathletes and single-sport athletes. The triathletes in the present study had a higher percent body fat than elite swimmers and runners (McArdle et al., 1978; Pollock et al, 1977; Wilmore & Bergfield, 1979), and competitive cyclists and runners (Burke, 1980; Costill, 1973; Foster et al., 1977; Hagberg et al., 1979), as well as, triathletes (Holly et al., 1986; O'Toole et al., 1987). As expected, they had a lower percent body fat than recreational swimmers (Gergley et al., 1984) since their training also includes cycling and running.

A number of triathlon studies (Holly et al., 1986; O'Toole et al., 1987; Rogers et al., 1986; van Rensburg et al., 1984)) indicate race times were more related to relative VO_2 max than absolute VO_2 max. In triathlons, eighty percent of the race is spent in activities related to body weight since both cycling and running oxygen cost are a function of body weight (Adams et al., 1982; Burke, 1980). Housh (1986) found a significant ($p < .001$) positive correlation ($r = 0.48$) between body weight and run times indicating heavier subjects were slower runners. He also suggested increased adiposity negatively affected running performance. Similarily, Costill (1967) reported a significant association ($p < .10$) between percent body fat and running performance ($r = -.43$), as well he noted faster runners had gross body weights that were much less than slower runners. Holly et al, (1986) found the successful triathlete had a low percentage body fat resulting in a greater percent of total body weight that is working muscle, and thus a greater relative oxygen utilization.

Significant negative correlations ($p < .05$) between percent body fat and weight-corrected VO_2 max were found for both cycling ($r = -.40$) and running ($r = -.42$) in the present study. This was to be expected since both cycling and running are weight dependent and a higher percent body fat could slow performance.

Maximal Oxygen Uptake and Related Indices

The mean values of various physiological variables obtained at VO_2 max by the triathletes during tethered swimming (TS), cycle ergometry (CE), and thredmill running (TR) are presented in Table 3.

Maximal oxygen uptake values were highest on the TR and lowest on the TS. TS values ranged from 48.2 to 59.2 $ml.kg.^{-1}min^{-1}$ (3.35 to 4.35 $l.min^{-1}$) with a mean of 54.7 ± 4.3 $ml.kg.^{-1}min^{-1}$ (3.84 ± 3.4 $l.min^{-1}$). On the CE values ranged from 50.9 to 72.4 $ml.kg.^{-1}min^{-1}$ (3.77 to 4.78 $l.min^{-1}$) with a mean of 61.9 $ml.kg.^{-1}min^{-1}$ (4.34 ± .27 $l.min^{-1}$). At maximal oxygen uptake in TR, values ranged from 58.2 to 70.1 $ml.kg.^{-1}min^{-1}$ (3.93 to 4.98 $l.min^{-1}$) with a mean of 64.1 ± 4.1.$ml.kg.^{-1}min^{-1}$ (4.50 ± .30 $l.min^{-1}$). The CE values ml.kg-1.min-1 (l.min-1) were not significantly different from the TR, however, the TS values were 88.4% (71.0%) of the CE values and 85.3% (85.3%) of the TR values. These differences were significant $r = .27$ ($r = .49$) at a $P < .001$ level of significance.

A comparison of mean reported VO_2 max in male swimmers, cyclists, runners, and triathletes is presented in Table 4.

Maximal aerobic power has been measured and reported for many groups of elite, competitive, and recreational athletes, as well as, healthy sedentary individuals. The highest value obtained by a male athlete was 94 $ml.kg.^{-1}min^{-1}$ (Bergh et al., 1978). Although the average maximal oxygen uptakes for the triathletes are lower than those of elite swimmers, cyclists, and runners, one subject from the present study (subject # 7) with the highest swimming VO_2 max value of 4.35 $l.min^{-1}$ compares well to the values reported by Bonen et al, (1980) (4.36 $l.min^{-1}$). The individual (subject # 9) with the highest

TABLE 3. Mean (±SD) values and percentages of subjects during maximal tethered swimming (TS), cycle ergometry (CE), and treadmill running (TR)

VARIABLE	TS	TS% CE	TS%TR	CE	CE%TR	TR
VO2 max ($ml.min^{-1}.kg^{-1}$)	54.7**** (±4.3)	88.4	85.3	61.9 (±6.0)	96.6	64.1 (±4.1)
VO2max ($l.min^{-1}$)	3.84 (±.34)	71.0	85.3	4.34 (±.27)	96.4	4.50 (±.30)
VE BTPS ($l.min^{-1}$)	128.0**** (±1.8)	77.0	81.0	166.0 (±1.9)	105.0	158.0 (±1.6)
HR (bpm)	172**** (±6.7)	92.5	92.0	186 (±5.8)	98.4	189 (±8.6)
R	1.13* (±.04)	105.6	105.6	1.07 (±.06)	100.0	1.07 (±.05)
RPE	19.9 (±.30)	101.0	99.5	19.7 (±.69)	99.5	19.8 (±.41)

**** TS < CE,TR .001

*TS > CE, TR .05

TABLE 4 . Mean reported maximal oxygen uptake ($ml.min^{-1}.kg^{-1}$) in male swimmers cyclists, runners, and reported values of triathletes.

Sport	VO2 max	References
Swimmers	59.6{TS}	Bonen et.al, 1980;Holmer,I.1972; Holmer et al,.1974;Smith et al, 1984
Cyclists	74.0 {CE}	Astrand & Rohdahl, 1970; Burke, 1980; Saltin & Astrand, 1967
Runners	78.8 {TR}	Astrand & Rohdahl, 1970; Pollock et al, 1977; Saltin & Astrand, 1967
Competitive Triathletes		**Present study**
	54.7 {TS}	
	61.9 {CE}	
	64.1 {TR}	
Triathletes	30.4 {SB}	Albrecht et al, 1987
	56.3 {CE}	
	57.6 {TR}	
	56.7 {FS}	Dengel et al, 1986
	63.2 {CE}	
	65.3 {TR}	
	52.5 {TS}	Kohrt et al,.1987
	57.9 {CE}	
	60.5 {TR}	
	57.9 {TR}	Kreider et al,.1988
	55.0 {TR}	Rogers et al,.1986
	54.6 {TR}	van Rensburg et al., 1984
Ironman Triathletes	72.0 {TR}	Holly et al,.1986
	58.4 {TR}	
	68.8 {TR}	O'Toole et al,.1987
	66.7 {CE}	
	49.1 {AM}	

TS - tethered swimming
CE - cycle ergometry
TR - treadmill running
AM - arm ergometry
SB - swim bench
FS - free swimming

cycling value 4.78 $l.min^{-1}$ (72.4 $ml.kg.^{-1}min^{-1}$) compares favorably with the previously reported values. None of these triathletes compared well to elite runners.

In previous studies of triathletes, Holly et al, (1986) reported VO_2 max.for four 'elite' triathletes on the treadmill of 72 $ml.kg.^{-1}min^{-1}$ whichcompared favorably to values of elite runners (78.8 $ml.kg.^{-1}min^{-1}$), cyclists,(74 $ml.kg.^{-1}min^{-1}$) and swimmers (59.6 $ml.kg.^{-1}min^{-1}$) and for two 'other triathletes' (58.4 $ml.kg.^{-1}min^{-1}$) which was less than the mean of the present study (64.1). Similarly, Dengel et al, (1986), Kohrt et al, (1987), Kreider et al, (1988), and Rogers et al, (1986), obtained lower VO_2 max values of 65.26, 60.5, 57.9 and 55.0 ($ml.kg.^{-1}min^{-1}$) respectively, on the TR for their group of triathletes. These values are compared to those found in the present study. Dengel et al, (1986), Kohrt et al, (1987), and O'Toole et al, (1987) measured VO_2 max utilizing cycling ergometry and reported values of 63.15, 57.9, and 66.7 $ml.kg.^{-1}min^{-1}$. The cycling values from this study (61.9 $ml.kg.^{-1}min^{-1}$) are also comparable to those previously studied.

The tethered swimming values of the present study (54.7 $ml.kg.^{-1}min^{-1}$) are higher than those of Kohrt et al, (1987) utilizing similar methodology, but lower than those of Dengel et al, (1986) who utilized flume swimming which has been shown to elicit comparable values to tethered swimming (Bonen et al, 1980). The present values were higher than either O'Toole et al (1987) and Albrecht et al (1987), since both utilized modes (arm ergometry and swim bench) which have been shown to elicit lower values (Bonen et al, 1980).

Maximal oxygen uptake values are generally conceded to be highest when the largest muscle mass is used and trained movement patterns is utilized in the test (Astrand & Rodahl,1970).

TR values in all of the studies presented are higher then CE or TS values. A number of researchers (Astrand & Rodahl, 1970; McArdle et al., 1981; Newton, 1963; Taylor et al., 1955) have reported higher VO_2 max values on the TR as compared to the CE. Factors observed to be primarily responsible for the higher values are:

1) musculature employed and nature of the specific task (Holmer & Astrand, 1971; Magel et al., 1975; McArdle et al., 1978; Smith & Kempire, 1984)

2) higher maximal heart rate (Taylor et al., 1955).

3) body position (Holmer, 1972).

4) conditions for heat exchange (King, 1967).

5) degree of training (Holmer et al, 1974).

6) differences in the oxidative capacities of the muscles employed (Bonen, 1980; Nygaard & Nielson, 1978).

CE values are usually 9 to 11% less than TR values unless the athletes is a well-trained cyclists (Astrand & Rodahl, 1970; McArdle at al., 1981). O'Toole et al, (1987) found cycling values to be 3 % and 4.3 % less than TR values. CE values in the present study ranged from 5 % higher to 10.5% lower than TR

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The extent to which VO_2 max plays a key role in the successful performance of triathletes and single sport athletes remains uncertain. Just as O'Toole et al, (1987) and other researchers' data suggest, there is perhaps some critical level below which triathletes will not be successful, but above which other factors play a more important role in performance. For example, Rogers et al, (1986) studied 21 male triathletes performing 20 km canoeing, 90 km cycling, and 42 km running. They found that cortisol levels after the race showed a significant correlation with VO_2 max. The subject with the lower VO_2 max tended to show a greater increase in cortisol levels. The authors believed the cortisol levels reflected a greater physiological and probably psychological exposure to stress during the race than those with higher maximal oxygen uptakes. In another study, O'Toole et al, (1987) found a subject with the lowest VO_2 max who finished third in the Ironman triathlon as well as another triathlete with a lower than expected VO_2 max for endurance athletes who finished eighth in his age group. A case in point from the present study is subject #3 with a low VO_2 max in all three sports. He typically finishes well ahead of all other subjects in this study except for subject #1. The importance of VO_2 max at VT and other 'factors' having a role in performance appear to be substantiated.

The mean maximal ventilation values at VO_2 max (Table 3) for TS, CE, and TR were 128 ± 1.8, 166 ± 1.9, and 158 ± 1.6 $l.min^{-1}$, respectively (Table 3). Peak maximal heart rate for TS ranged from 158 to 182 beats per minute (bpm) with a mean of 172 ± 6.7 bpm; for CE from 178 to 198 bpm with a mean of 186 ± 5.8 bpm; and for TR from 180 to 209 bpm with a mean of 189 ± 8.6. There were significant differences ($P < .001$) between maximal ventilation ($r = .33$) and heart rate values($r = .48$) obtained for TS and CE, and TS and TR with no significant difference between CE and TR values.

The lower maximal values for pulmonary ventilation found in TS as compared to CE and TR are well documented and discussed in previous literature (Faulkner, 1968; Holmer, 1972; Holmer & Astrand, 1972; Magel & Faulkner, 1967; McArdle et al., 1971). Dengel (1986), Kohrt et al, (1987),and O'Toole et al, (1987) in their studies of triathletes found lower pulmonary ventilation values in TS, as compared to CE and TR. The decreased ventilation values are probably due, in part, to the lower VO_2 max values.

The lower maximal heart rate values in TS as compared to CE and TR found in the present study compare to the results of previous literature (Astrand & Saltin, 1961; Faulkner, 1968; Holmer, 1972; Holmer & Astrand, 1972; Magel &

Faulkner, 1967; Magel et al., 1969; McArdle et al., 1971; 1978). Lower maximal heart rate values have also reported in a number of triathletes studies (Dengel et al., 1986; Kohrt et al., 1987; O'Toole et al., 1987).

The factors which may account for the effect on heart rate in TS may be similar to those effecting VO_2 max values. Another possible explanation might be diving bradycardia.which results in a lowering of the heart rate due to face immersion. The diving reflex is a well-known phenomenon in a number of mammals and it has also been reported by Irving (1963) and Scholander et al, (1962) in men during diving. Although the respiratory pattern in swimming is different than diving, the mechanism may have an effect on heart rate values reported in maximal swimming. Kohrt et al, (1987) suggests maximal heart rate may be lower because the zero gravity of water and the supine body position increases central blood volume and stroke volume.

Cardiac output and heart rate may also be reduced in the water environment via a reduction in thermoregulatory demand. This is the most probable reason for decreased heart rates in TS. A decreased amount of active muscle mass (Astrand & Saltin, 1961; Bergh, 1976; Sternberg, 1967) may influence the heart rate response since swimmers rely predominantly on upper body musculature. Holmer (1972) suggests the relative contribution of these factors is unknown, but the lower maximal heart rate response during swimming has been well documented in elite and recreational swimmers and does not appear to be modified by training.

The mean maximal R values for TS, CE, and TR were $1.13 \pm .04$, $1.07 \pm .06$, and $1.07 \pm .05$, respectively (Table 3). These values were significantly different ($r = .51$) at a $P < .05$ level of significance for TS and CE, and TS and TR, with no significant difference between CE and TR.

The mean maximal R values in this study for CE and TR compare with the results in previous literature, however the mean maximal R values for TS (R = 1.13) in this study are not in agreement with the literature. In previous literature (Holmer, 1972; Kearney, 1976; Lafontaine et al., 1982; Smith et al., 1984) it has been suggested that hypoventilation during swimming results in an R value lower than 1.0. One triathlete study (Kohrt et al., 1987) has obtained a significantly lower ($P < .01$) R value ($R = .99$) for TS as compared to CE and TR. The swimmers in this study tended to hyperventilate perhaps due to anxiety resulting from inexperience with the breathing apparatus. Other possible explanations include: 1) the subjects in previous research were possibly fatigued and unable to perform maximally, 2) the present study subjects were well-rested and able to maximally stress themselves further, and 3) perhaps there is also some unknown training factor due to the variabilty in training which may cause the triathletes to have an increased R value in swimming.

Maximal Ratings of Perceived Exertion

The mean maximal ratings of perceived exertion for TS, CE, and TR were $19.9 \pm .03$, $19.7 \pm .69$ and $19.8 \pm .41$, respectively corresponding to 'very, very hard' (Table 3). These were not significantly different ($r = .30$) and compare favorably to Purvis and Cureton (1981) who found a mean maximal RPE at VO_2 max during cycling to be 19.9 corresponding to 'very, very hard'. Based upon the linear relationship between heart rate and increasing exercise intensity and subjective decisions to stop exercising at a maximal level (i.e. maximal heart rate) it seems plausible for subjects to perceive the maximal workload as 'very hard' or 'very, very hard' in each sport. In fact using a rigorous training program

(5-7 days per week of running), Ekblom and Goldbarg (1971) examined changes in RPE when intensity of exercise was adjusted relative to VO_2 max at submaximal workloads. RPE was lower by 1.5 to 2.0 points following training, but maximal RPE did not differ. Also, Kilbom (1971) reported no difference as a result of training in RPE at exhaustion.

However, some authors suggest as a consequence of training, individuals experience different degrees of physical stress during intense activity.and as such may rate maximal exercise at lower levels than others. For example, Morgan and Pollock (1977) found at speeds above 10 mph, the less fit runners did rate their effort significantly higher. In a study of 18 hockey players during treadmill exercise, Rosentseieg et al, (1979) reported players rating maximal workloads as 'somewhat hard' (13.6) on the Borg scale while exercising at heart rates of 180 bpm. They suggest the players were sufficiently accustomed to highly vigorous exercise to exhibit lower RPE values for a given workload.

Although the mean RPE's in this study indicate ratings of plus 19.7, some subjects in the present study rated maximal exercise at an RPE of 18 and 19 suggesting perhaps state of training does effect maximal RPE ratings. For example, subject # 9 rated maximal cycling at an RPE of 18. He possessed the highest cycling VO_2 max, a high VT @ VO_2 max, and ranked cycling first.

The RPE in CE and TR correlated at a $P < .001$ level of significance ($r = -.61$ and $-.59$) with VO_2 max. The correlations support the relationship of perceptual ratings increasing linearly with power output and metabolic stress (Skinner et al., 1973). However, the insignificant correlations between maximal heart rate and RPE @ VO_2 max in the present study ($r = -.14, -.31, .06$) provide some contradicting evidence for the moderately high correlations previously found between RPE and heart rate (Borg, 1973; Skinner et al., 1973). Lower maximal heart rates and maximal oxygen uptake values may have contributed to the lack of correlations.

__Ventilatory Threshold__

Figure 2 depicts the mean VT percentage of VO_2 max in each sport.Examples of ventilatory threshold (VT) detection in tethered swimming (TS), cycle ergometry (CE), and threadmill running (TR) are presented in Figures 3a, 3b, and 3c. Ventilatory threshold detections for all subjects are in Appendix C.

The mean values and percentages of various physiological variables obtained at VT by the triathletes during TS, CE, and TR are presented in Table 5.

Mean oxygen uptake values obtained at VT were highest on the TR and lowest on the TS. At ventilatory threshold in TS, weight-corrected oxygen uptake values ranged from 29.8 to 51.6 $ml.kg.^{-1}min^{-1}$ (1.75 to 3.79 $l.min^{-1}$) with a mean of 42.1 ± 6.0 (2.98±.59 $l.min^{-1}$). On the CE the values ranged from 36.3 - 58.7 $ml.kg.^{-1}min^{-1}$ (2.74 to 4.09 $l.min^{-1}$) with a mean of 47.3 ± 7.1 $ml.kg.^{-1}min^{-1}$ (3.31 ± .40 $l.min^{-1}$). At ventilatory threshold in TR, values ranged from 49.3 to 61.4 $ml.kg.^{-1}min^{-1}$ (3.10 to 4.36 $l.min^{-1}$) with a mean value of 54.8 ± 3.4.$ml.kg.^{-1}min^{-1}$ (3.84 ± .38 $l.min^{-1}$). The TS values (l.min-1) which were 76.8% of TR values were significantly lower (r = .50) at a P< .01 level of significance. No differences were obtained between TS and CE (89%), and CE and TR (86.3%).

Most of the literature on ventilatory threshold has concentrated on the validation of protocols, methodology, detection, possible mechanisms, and training applications. As such, little specific comparable data is available.

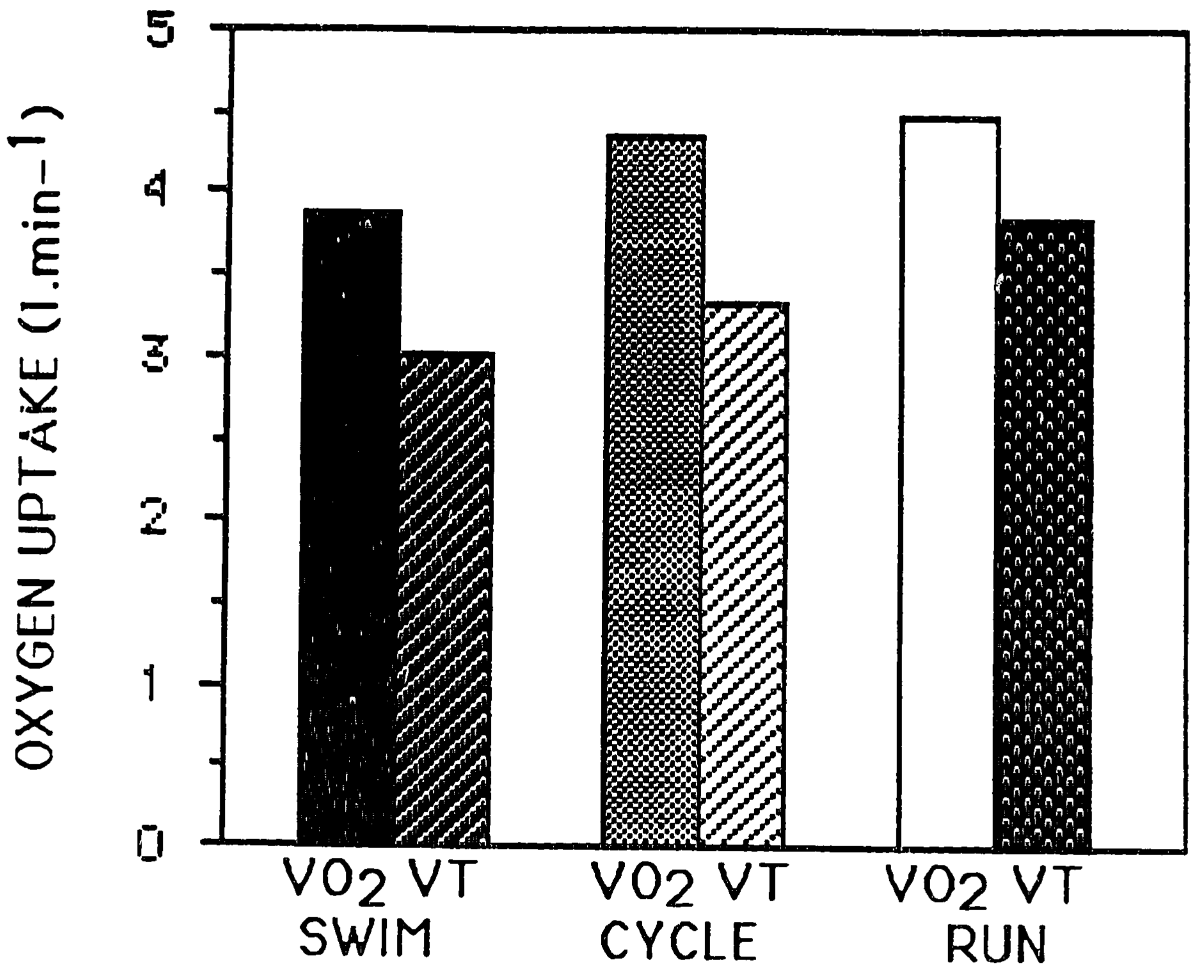

Figure 2. Mean maximal oxygen uptake (VO_2 max and ventilatory threshold in swimming cycling, and running.

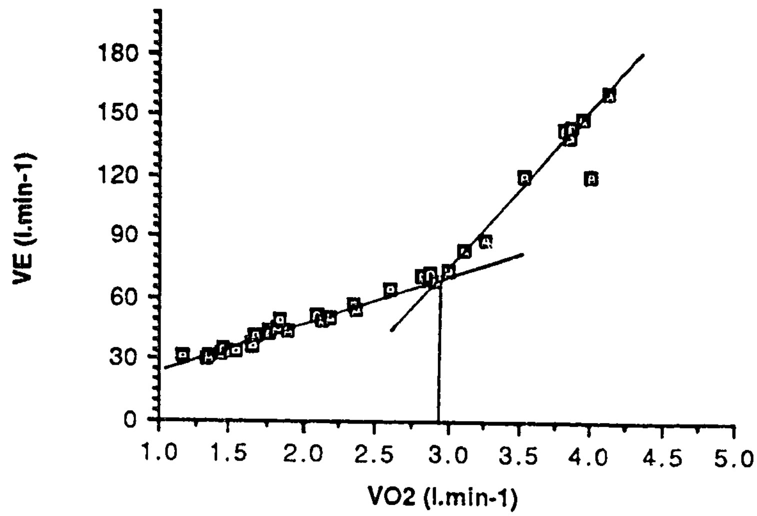

Figure 3a. Ventilatory threshold detection in tethered swimming .

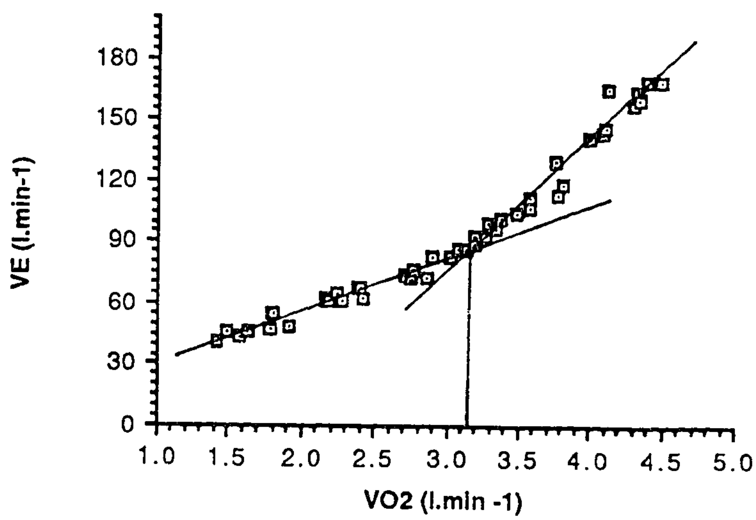

Figure 3b. Ventilatory threshold detection in cycle ergometry

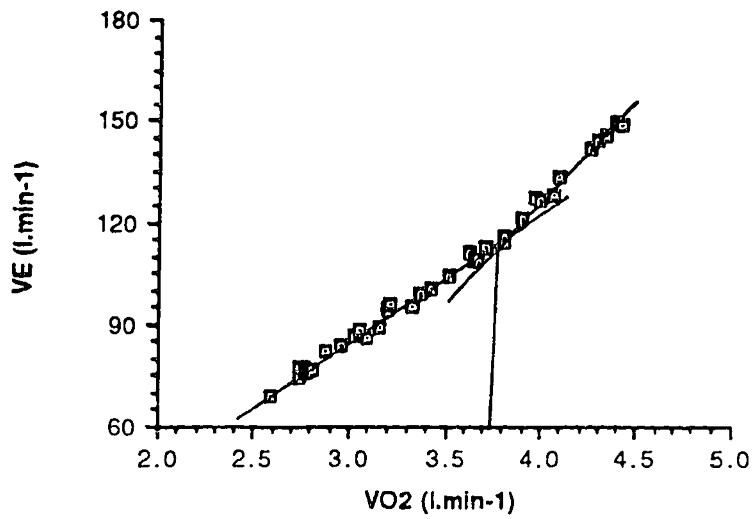

Figure 3c. Ventilatory thresho;d detection in treadmill running.

TABLE 5. Mean (±SD) values and percentages for subjects during ventilatory threshold in swimming (TS), cycle ergometry (CE), and treadmill running (TR).

VARIABLE	TS TR	TS%	CE	TS%TR	CE	CE%TR
VO2@VT (ml.min .kg)	42.71** (±6.0)	89.0	76.8	47.3 (±6.0)	86.3	54.8 (±4.1)
VO2@VT ($l.min^{-1}$)	2.98** (±.59)	90.0	77.6	3.31 (±.40)	86.0	3.84 (±.38)
VE BTPS (l.min)	77.9* (±18.6)	92.5	72.8	84.2 (±11.8)	78.7	107 (±15.1)
HR (bpm)	154**** (±9.6)	95.1	89.1	163 (±9.5)	93.7	174 (±9.8)
R	1.02*** (±.06)	118.9	118.9	.95 (±.05)	100.0	.95 (±.04)
RPE	14.2 (±2.7)	91.0	88.2	15.6 (±1.3)	96.9	16.1 (±1.5)

****	TS < TR & CE < TR	.001
***	TS > CE, TR	.001
**	TS < TR	.01
*	TS < TR & CE < TR	.05

TABLE 6 . Reported ventilatory threshold in male swimmers, cyclists, runners, and triathletes.

Literature	VT (ml.kg-1.min-1)	% of VO2	References
Swimmers	59.6{TS}	90.4	Smith et al, 1984
	39.6{TS}	65.9	
Cyclists	27.0{CE}	70.1	Dwyer & Bybee, 1983
	35.9{CE}	61.1	Lopategui et al, 1986
	26.4{CE}	63.4	Simon et al, 1983
	43.7{CE}	79.5	Withers et al, 1981
Runners	63.9{TR}	85.3	Bunc et al, 1986
	*	79.2	DeMello et al, 1987
	50.2{TR}	74.6	Tanaka et al, 1984
	37.8{TR}	75.2	Withers et al, 1981
Triathletes	**42.7 {TS}**	**78.0**	
	47.3 {CE}	**76.0**	
	54.8 {TR}	**85.0**	**Present study**
	15.7 {SB}	51.6	
	44.3 {CE}	78.8	
	45.7 {TR}	79.0	Albrecht et al, 1986
	45.2 {TR}	82.8	van Rensburg et al,.1984

TS - tethered swimming
CE - cycle ergometry
TR - treadmill running
SB - swim bench
* - not available

However, Table 6 does present some comparable VT values and percentages of VO_2 max in male swimmers, cyclists, runners, and triathletes.

The present results are in agreement with previous literature which states that endurance athletes have a high ventilatory threshold. Smith et al, (1984) based upon TS, found the VT's of two groups swimmers. The endurance trained swimmers mean VT's which were 90.4% of VO_2 max which according to the authors was 'dramatically high' and the sprint trained swimmers had mean VT's which were 65.9% of VO_2 max. The mean of both groups is 78.2% as compared to 78% in the present study.

Dwyer and Bybee (1983), Lopategui et al, (1986), Simon et al, (1983), and Withers et al, (1981) utilizing CE found the VT of cyclists were 70.1, 61.1, 63.4, and 79.5 % of VO_2 max.respectively, as compared to 76% of VO_2 max in the present study.

Bunc et al, (1986), DeMello et al, (1987), Tanaka et al, (1984), and Withers et al, (1981) have noted VT's of 85.3, 79.2, 74.6, and 75.2% of VO_2 max respectively, in runners measured on TR as compared to 85% of VO_2 max in the present study.

VT, like VO_2 max, is highest on the TR, followed by the CE and TS values. Factors observed to be primarily responsible for the higher values, are similar to those affecting VO_2 max, as well as those factors responsible for increases in VT resulting from training. For example, smaller muscle groups have to work under partly anaerobic conditions, even if the oxygen uptake is relatively low. The exception is with highly trained swimmers who have blood lactate levels which tend to stay low until energy demand approaches the VO_2 max (Holmer, 1972).

The VT of triathletes has been minimally discussed in previous literature.

Van Rensburg et al, (1984) suggests the oxygen uptake at the lactic acid turnpoint (anaerobic threshold) is the determining factor for the prediction of success in triathlons. This view is based upon the high correlations between the VO_2 at lactic acid turnpoint and performance in each of canoeing, cycling, and running. This data may be limiting, since all measurements were compared to values obtained only on a treadmill.

Albrecht et al (1986) utilized similar protocols in cycling ergometry and treadmill running to those of the present study. The cycling results of the present study (76% of VO_2 max) are comparable to those of Albrecht et al, (1986), (78.8% of VO_2 max) but the treadmill running results (85% of VO_2 max) are superior (79% of VO_2 max).

Because triathletes are faced with the difficult task of developing their ventilatory thresholds in three sports, it is difficult to compare any one group to another. Each individual comes from a different background of experience and training. Viewed as a single sport i.e. mean ventilatory threshold of all three sports, Albrecht et al, (1986) demonstrated a mean of 69.8% of VO_2 max which is low due to the included swim bench values. The present study demonstrated a mean of 79.7% of VO_2 max. The present study triathletes possessed high ventilatory thresholds and are comparable to swimmers, cyclists, runners, and other triathletes.

The mean minute ventilation volumes at ventilatory threshold in TS, CE, and TR were 77.9 ± 18.6, 84.2 ± 11.8, and 107.4 ± 15.1 $l.min^{-1}$, respectively (Table 5). The mean heart rate at ventilatory threshold in TS was 154 ± 9.6 beats per minute (bpm) with a range of 130 to 170 bpm; in CE 163 ± 9.5 bpm with a range of 143 to 179 bpm; and in TR 174 ± 9.8 bpm with a range of 162 to 196 bpm (Table 5). There were significant differences between mean minute ventilation volumes r = .925 (P< .001) and heart rate r = .415 (P< .001) values obtained for TS and TR, and CE and TR, but there were no differences between TS and CE. The differences between TS and TR reflect ventilatory threshold differences. Perhaps the difference between CE and TR, although not reflective of ventilatory threshold differences, may be due to the varying size of muscle mass utilized in each testing mode. These differences are reflected in maximal oxygen uptake values as well.

The ratings of perceived exertion and R values for TS, CE, and TR were 14.2 ± 2.7 and 1.02 ± .06, 15.6 ± 1.3 and .95 ± .05, and 16.1 ± 1.5 and .95 ± .04 respectively (Table 5).

The R values were significantly different r = .430 at a P< .001 level of significance for TS and CE, and TS and TR. These differences are analagous to those found at VO_2 max in the present study as well as those of Kohrt et al, (1987).

Table 7 presents HR @ VT and RPE @ VT in each sport. The RPE values at ventilatory threshold in TS are in agreement with those found in the literature which corresponded to between '12' and '14' (Bellew et al., 1983; DeMello et al., 1987; Dressendorfer et al., 1981; Purvis et al., 1981; Simon et al., 1983). Those found in CE (15.6) and TR (16.1) are somewhat higher than those in the literature. Albrecht at al., (1986) utilizing a revised RPE scale found VT in CE and TR corresponding to RPE's of '5.4' and '5.0', respectively which correspond to approximatley '15' on the original Borg scale (Carton & Rhodes, 1985). Since other researchers have reported discrepancies in RPE response at a given heart rate on varying modes of exercise (Michael & Hackett, 1972; Sidney & Shepard,

TABLE 7. Heart rate and RPE at Ventilatory Threshold in each sport.

SUBJECT NO.	Sport	HR @ VT swim	HR @ VT cycle	HR @ VT run	RPE @ VT swim	RPE @ VT cycle	RPE @ VT run
1.	Swimmer	170	168		17.5	17	
2.	Cyclist	141	160	170	12	15	15
3.	Triathlete	159	172	175	14	17	17
4.	Cyclist	156	171	175	15.5	15	15
5.	Runner	153	153	166	13	14.5	16
6.	Triathlete	165	165	179	18	14.5	18
7.	Runner	161	163	196	16	14.5	15
8.	Cyclist	151	179	180	17	18	19
9.	Runner	146	166	162	14	17	16
10.	Triathlete	148	157	179	9	15.5	17
11.	Swimmer	159	162	164	12	15	14.5
12.	Swimmer	138	143	166	13	14	15
Mean		154	163	174	14.2	15.6	16.1

1977) it suggests that although the RPE @ VT were higher in this study in CE and TR, these findings are in order.

The discrepancy in RPE response at a given heart rate on varying modes of exercise was substantiated by a few subjects in the present study. For example, subject #5's VT was detected at 153 bpm in both TS and CE , but he rated TS at '13' and CE at '14.5'. A greater discrepancy was found in subject #6 who's VT was detected at 165 bpm in both TS and CE , but he rated TS at '18' and CE at '14.5'. This may be a reflection of prior sport experience. For example, subject # 6 had no significant swimming experience and he ranked swimming third suggesting he was more uncomfortable and found the sport more difficult than cycling.

Subject # 7 displayed a remarkably high heart rate (196 bpm) at ventilatory threshold in treadmill running. This corresponded to his age predicted maximum, however he was able to attain a maximum heart rate of 209 bpm which was very high for a 25 year old individual.

An interesting finding in this study was subjects who rated their RPE at VT the same but the corresponding heart rates were very different. For example, subject #4 rated TS at '15.5', CE at '15', and TR at '15', but the heart rates were 156, 171, and 175, respectively. Subject #2 rated CE and TR at '15' but the heart rates were 160 and 170, respectively and subject #6 rated TS and TR at '18', but heart rates were 165 and 179, respectively. These individuals appear unable to use RPE @ VT as a training tool in each sport. This was substantiated with the HR @ RPE results. Subject #4 for example, had HR's @ RPE of 156, 162, and 170. He would be able to use RPE in TS, but not in CE and TR. Subject #2 had corresponding HR's @ RPE in CE and TR of 154 and 159 respectively, neither of which seem useful and subject #6 had corresponding HR's @ RPE in TS and TR of 159 and 174, neither which seem useful. Comparison to field tests using the heart rate monitors is inappropriate since each subject in random assignment performed in the sport which they had been able to utilize the RPE. Future research would benefit from testing subjects in the field in each mode. Heart rates should typically be different in each mode due to the varying amounts of acting muscle and body position, as should the RPE which makes it difficult for triathletes to train in each sport according to an assigned RPE. Only one subject (# 9) was able to utilize RPE in more than one sport.

The suggested linear relationship between heart rate and RPE was somewhat substantiated in the present study. When the mean data was analyzed at ventilatory threshold, a legitimate tracking of heart rate and RPE was noted. However statisical analysis revealed while there were significant correlations between HR @ VT and VT (l.min -1) in each sport (r = .74, .35, .81), there were no significant correlation between HR @ VT and RPE @ VT in TS and TR.(.17 and -.21) Thus some support is provided for those researchers who dispute the existence of a linear relationship between heart rate and RPE (Davies & Sargeant, 1979; Ekblom & Goldbarg, 1971).

Training Specificity

An understanding of each subjects significant sport experience (SSE), significant sport ranking (SSR), and triathlon experience (TE) may help reduce the possibility of extraneous factors such as motivation level, tolerance level for discomfort and pain, and testing error from effecting the subjects VT and VO_2 max results, as well as, their ability to train utilizing the RPE @ VT and the HR/MON. In addition, this information will contribute to the evidence in the literature which support the concept of training specificity. Table 8 presents each individuals SSE, SSR, and TE.

If a subject had participated or competed in primarily one of either swimming, cycling, or running previous to their triathlon training, this was considered a significant sport experience (SSE). If a subject had not previously competed in any of the three sports but had begun training for all three in order to race triathlons, this was considered triathlon experience.

Each individual was also ranked on the three sports in terms of amount of previous training in each sport prior to the study. This was termed significant sport ranking (SSR). For example, an individual who may have had a competitive swimming background but had low priorities in swim training, would possibly not have as developed a VT or VO_2 max or the ability to train with RPE versus HR/MON.

The years of triathlon experience (TE) were considered to be the years in which the individual had competed in the sport .

VO_2 max and VT values along with rank orders for each subject are presented in Table 9 and 10. Table 11 presents individual VT percentages of VO_2 max in TS, CE, and TR.

With few exceptions individuals who have previous training in a particular sport and who have concentrated their training efforts on that sport have good results in that sport. This is in agreement with Kohrt et al (1987) who suggests triathletes undergo specific adaptations to training based upon reduced decrements in VO_2 max between running and cycling, and running and swimming, as a result of training. Had a general training response been experienced, equal improvement in all areas might have been expected.

TABLE 8. Significant sport experience (SSE), significant sport ranking (SSR) and triathlon experience (TE).

Subject No.	SSE SWIM CYCLE RUN	SSR			TE (yrs)
1.	swimming	1	2	3	4
2.	swimming	1	3	2	3
3.	triathlons	2	3	1	6
4.	cycling	3	1	2	2
5.	running	2	3	1	10
6.	triathlons	3	2	1	3
7.	running	2	3	1	2
8.	cycling	3	1	2	5
9.	running	3	1	2	6
10.	triathlons	2	3	1	1
11.	swimming	2	3	1	3
12.	swimming	1	2	3	3

	SSE Summary				SSR Summary				
Mean:	Swim	Cycle	Run	Triathlons		Swim	Cycle	Run	4
	4	2	3	3	1.	3	3	6	
					2.	4	4	4	
					3.	5	5	2	

TABLE 9 . Individual maximal oxygen uptake values ($ml.min^{-1}.kg^{-1}$), rank order, and percentage of each sport for all subjects during tethered swimming, cycling, and running.

Subject No.	TS	RANK	% of TR	CE	RANK	% of TR	TR	RANK
1.	58.4	(5)		66.8	(3)		N/A	
2.	58.5	(4)	94.5	62.3	(6)	100.6	61.9	(8)
3.	48.2	(12)	82.8	50.9	(12)	87.5	58.2	(11)
4.	53.6	(7)	86.5	60.8	(7)	98.1	62.0	(7)
5.	51.3	(10)	75.0	64.5	(5)	94.3	68.4	(3)
6.	51.5	(9)	87.1	54.4	(11)	92.0	59.1	(10)
7.	59.2	(1)	94.1	57.5	(10)	91.4	62.9	(6)
8.	51.9	(8)	74.0	67.3	(2)	96.0	70.1	(1)
9.	59.0	(2)	85.5	72.4	(1)	105.0	69.0	(2)
10.	48.4	(11)	79.5	59.9	(8/9)	98.4	60.9	(9)
11.	58.6	(3)	87.6	59.9	(8/9)	89.5	66.9	(4)
12.	57.7	(6)	88.0	66.0	(4)	100.6	65.6	(5)

TABLE 10. Individual VT values (ml.min^{-1}.kg^{-1}), rank order, and percentage of each sport for all subjects during tethered swimming, cycling, and running.

Subject No.	TS RANK	TS%of CE	TS%of TR	CE RANK	CE%of TR	TR RANK
1.	51.6 (1)	114.5		51.2 (5/4)	N/A	
2.	41.3 (7)	93.9	77.5	44.0 (9)	82.6	53.3 (8)
3.	40.4 (8)	105.8	77.4	38.2 (11)	73.2	52.2 (9)
4.	41.5 (5)	81.1	77.1	51.2 (5/4)	95.2	53.8 (7)
5.	36.1 (11)	70.0	63.8	51.6 (3)	91.2	56.6 (4)
6.	48.6 (3/4)	120.0	98.6	40.5 (10)	82.2	49.3 (11)
7.	47.3 (2)	130.3	81.1	36.3 (12)	62.3	58.3 (2)
8.	39.2 (9)	68.2	63.8	57.5 (2)	93.6	61.1 (1)
9.	30.7 (12)	52.3	56.5	58.7 (1)	108.1	54.3 (5)
10.	38.3 (10)	86.1	67.0	44.5 (8)	77.8	57.2 (3)
11.	48.6 (3/4)	108.0	90.0	45.0 (7)	83.0	54.2 (6)
12.	41.4 (6)	84.7	78.9	48.9 (6)	93.9	52.1 (10)

TABLE 11. Individual VT versus VO2 max.values (ml.min $^{-1}$.kg $^{-1}$) and rank order of subjects during tethered swimming,cycling, and running.

Subj #	TS			CE			TR		
	VT	VO_2	% Rank	VT	VO_2	% Rank	VT	VO_2	% Rank
1.	51.6	58.4	88.4 (2)	51.2	66.8	76.6 (5)			
2.	41.3	58.5	70.6(10)	44.0	62.3	70.6(11)	53.3	61.9	86.1 (6)
3.	40.4	48.2	83.8 (3)	38.2	50.9	75.0 (7)	52.2	58.2	89.7 (3)
4.	41.5	53.6	77.4 (7)	51.2	60.8	84.2 (2)	53.8	62.0	86.8 (5)
5.	36.1	51.3	70.4(11)	51.6	64.5	80.0 (4)	56.6	68.4	82.7 (8)
6.	48.6	51.5	94.4 (1)	40.5	54.4	74.4 (8)	49.3	59.1	83.4 (7)
7.	47.3	59.2	79.9 (5)	36.3	57.5	63.1(12)	58.3	62.9	92.7 (2)
8.	39.2	51.9	75.5 (8)	57.5	67.3	85.4 (1)	42.6	59.0	72.2 (9)
9.	30.7	59.0	52.0(12)	58.7	72.4	81.1 (3)	54.3	69.0	78.7(11)
10.	38.3	48.4	79.1 (6)	44.5	59.9	74.3 (9)	57.2	60.9	93.9 (1)
11.	48.6	58.6	82.9 (4)	45.0	59.9	75.1 (6)	54.2	66.9	81.0 (9)
12.	41.4	57.7	71.8 (9)	48.9	66.0	74.1(10)	52.1	65.6	79.4(10)

Since VO_2 max only increases approximately 10 - 20 % in well-trained athletic individuals Kohrt et al (1987) would have benefited from measuring ventilatory threshold to determine it's applicability to triathletes. A number of studies provide significant correlations between VO_2 max and VT suggesting Kohrt et al's results can be reliably used for comparison. Examples of training specificity are clearly apparent in the present study. Subjects # 1, 2, 9, 11, and 12, who had previous swimming experience also had high VO_2 max in TS as compared to CE and TR.

One exception, subject # 7 who although not a swimmer, was able to attain a high VT relative to VO_2 max. This increased VT relative to VO_2 max may indicate less efficient stroke mechanics which would increase the stress and resulting training effects as opposed to individuals with very efficient strokes and thus less stress on the body.

In terms of cycling and running, again training specificity is apparent. The subjects with the greatest amount of prior experience in cycling (#1, 4, 8, 9) and in running (#3, 5, 9, 11) elicited the highest results.

Some individuals who were very well trained in one sport were sometimes well trained in the other sports. For example, subjects #1, 8, and 9, exhibited this phenomenon. This is due to the discipline and training level in all three sports based upon the individuals goals to perform well in all three. However, subjects (i.e # 5 & 7) who were good in one activity were not necessarily good in the others. This may be due to lack of training effort in a particular sport. Individuals who are regarded as 'triathletes' with no specific backgrounds who are good triathletes i.e. finish in the top 5 of the province, have similar VO_2 's and VT's in each sport, (# 3 & 4), probably because they train similarly in all three sports.

Rating of Perceived Exertion

Table 12 presents heart rate at ventilatory threshold in each sport and mean heart rate at HR @ RPE and HR @ HR/MON for each subject.

Figures 4a, 4b, and 4c depict examples of heart rate training field responses based upon the predetermined RPE in each of TS, CE, and TR. Results for all subjects are in Appendix G.

A visual inspection of the graphs of each subject in each sport reveals variable heart rate training responses to the RPE.

Figures 5a to 5f allows visual comparison of HR @ RPE with HR @ HR/MON in each of TS, CE, and TR. The HR/MON in each example given provided improved training intensity responses.

The visual comparisons indicate in swimming, three individuals (#1, 3, 4) were able to accomplish the task while one (#2) had difficulty.

In cycling, three individuals (#5, 6, 7) were able to accomplish the task while one (#8) trained at a higher intensity than prescribed. In discussion with this subject, the researcher revealed the individual purposely trained at a higher intensity for personal reasons. The fact that he was able to maintain such an intensity for forty minutes indicates that perhaps his VT was under estimated.

In running, two individuals (#9 & 11) were able to accomplish the task while one (#12) had difficulty due to fatigue. He had not been able to complete the study according to the design due to time commitments, thus hewas tested on all protocols within a five day period. This may have led to a degree of fatigue which limited his performance in the HR/MON feedback training session. The second individual (#10), although unable to train at VT was just below that point

TABLE 12. Heart rate at ventilatory threshold in each sport and mean heart rate at HR@RPE and HR @ HR/MON.

SUBJECT	HR @ VT (Laboratory)			HR @ RPE (Field test)			HR @ HR/MON		
NO.	swim	cycle	run	swim	cycle	run	swim	cycle	run
1.	170	168		161	173		171		
2.	141	160	170	143	154	159	141		
3.	159	172	175	165	172	177	155		
4.	156	171	175	156	162	170	158		
5.	153	153	166	156	159	155		156	
6.	165	165	179	159	165	174		163	
7.	161	163	196	170	152	186		164	
8.	151	179	180	152	163	168		181	
9.	146	166	162	153	168	165			163
10.	148	157	179	161	161	170			172
11.	159	162	164	162	147	171			167
12.	138	143	166	143	128	144			156

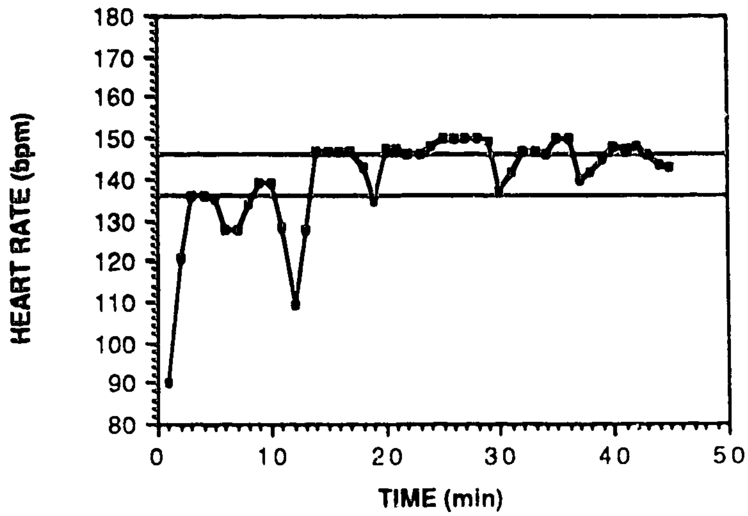

Figure 4a. Heart rate at rating of perceived exertion training response in field test swimming.

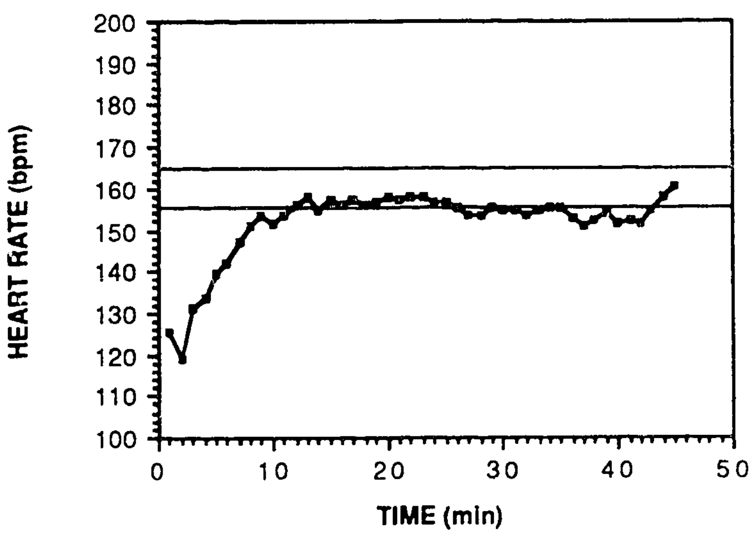

Figure 4b. Heart rate at rating of perceived exertion training response in field test cycling.

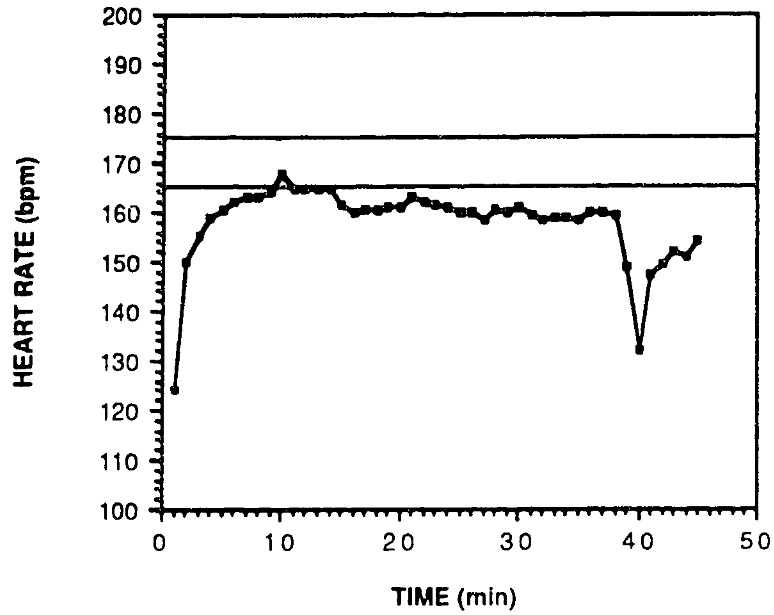

Figure 4c. Heart rate at rating of perceived exertion training response in field test running.

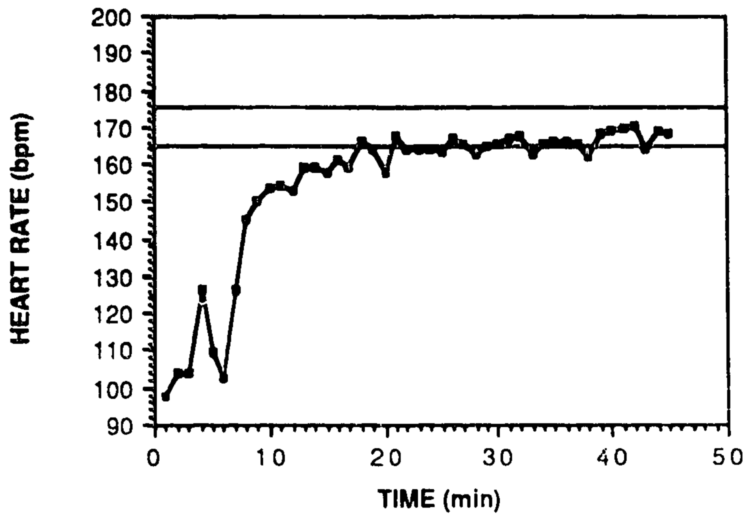

Figure 5a. Heart rate at rating of perceived exertion training response in field test swimming.

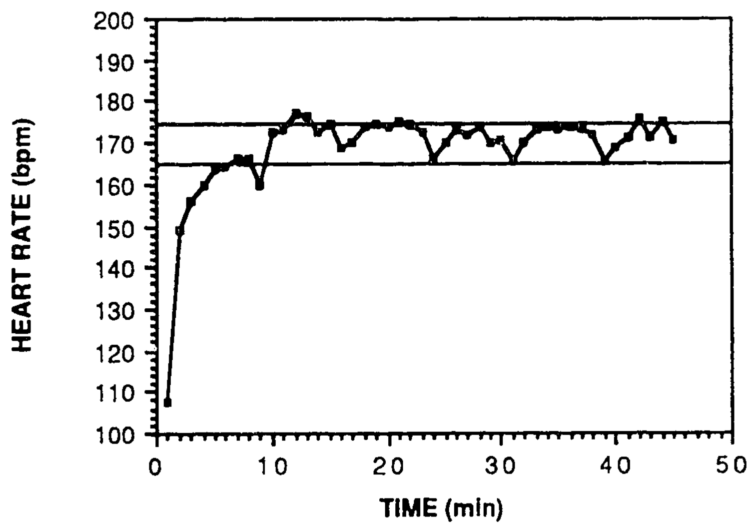

Figure 5b. Heart rate at heart rate monitor training response in field test swimming.

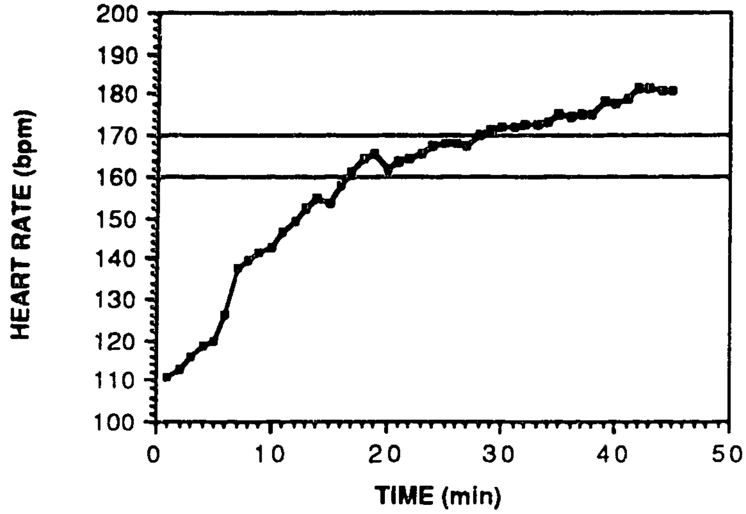

Figure 5c. Heart rate at heart rate monitor training response in response in field test cycling.

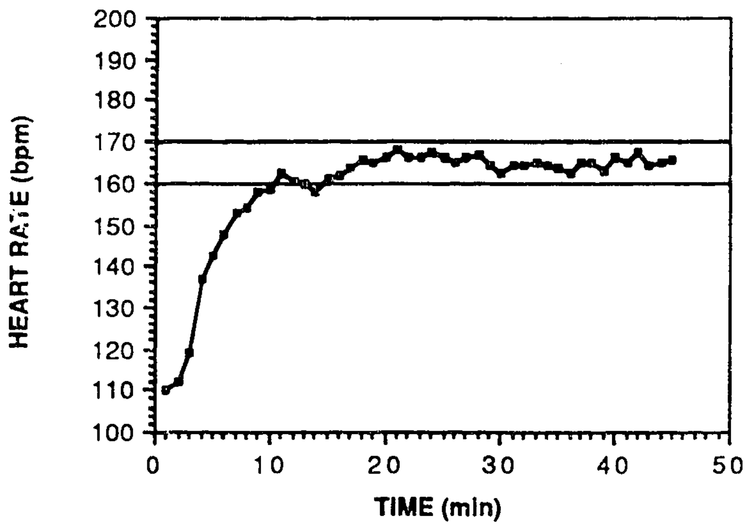

Figure 5d. Heart rate at heart rate monitor training response in field test cycling.

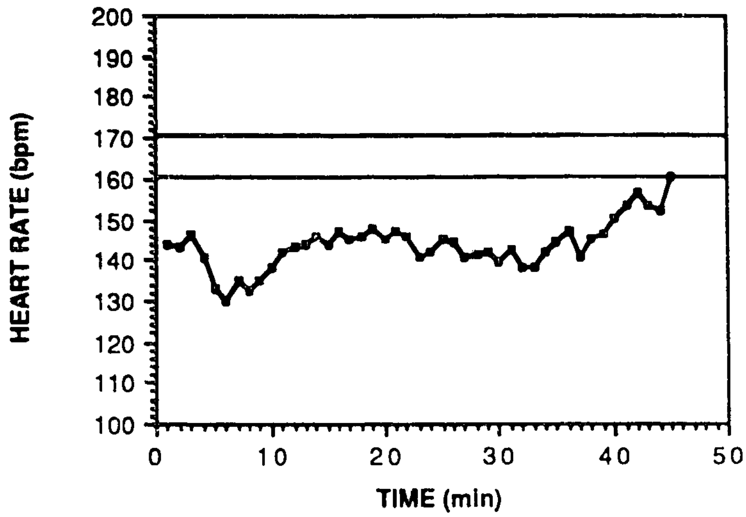

Figure 5e. Heart rate at rating of perceived exertion training response in field test running.

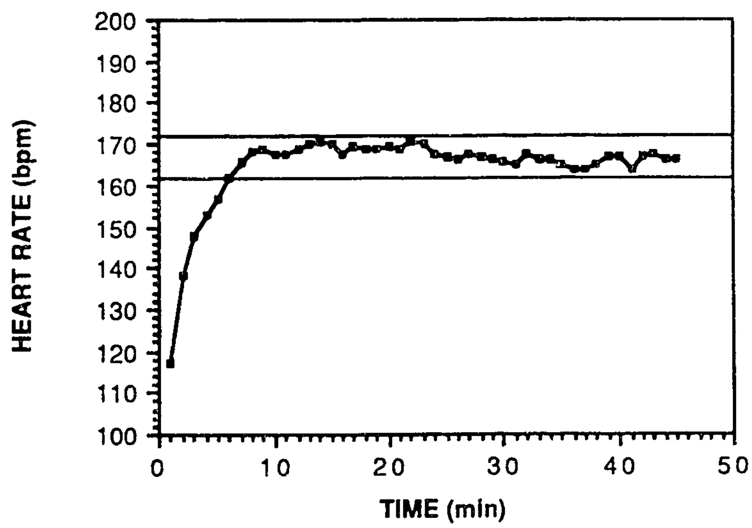

Figure 5f. Heart rate at heart rate monitor training response in field test running.

for the entire duration of testing. He may have been fatigued or his threshold may have been over estimated.

Figure 6 and Table 13 present percentage error between HR @ VT and mean HR @ RPE for each subject, in each sport, and percentage error between HR @ VT and mean HR @ HR/MON for each subject in a given sport.

Only two subjects (#4 & 6) did not improve their training by utilizing the heart rate monitor, however the difference between the RPE and the heart rate monitor was negligible.

Simple correlation, regression analysis, and stepwise regression analysis were performed on the data in order to determine which method best predicted the HR at VT. All methods confirmed:

1. the heart rate at RPE (HR @ RPE) provided a correlation of r = .569 and accounted for the common variance of R-sq = .323 with the HR @ VT. Neither value was significant.

2. the HR/MON provided a correlation of r = .927 and accounted for the common variance of R-sq = .860. which was significant at a P <.001 level of significance. Figures 7a and Figure 7b present percent variation predicted by HR @ RPE and HR @ HR/MON.

Representation of the mean data may have caused few differences to occur. For example, an individual may have been above and below his threshold at some point in the test, but the mean heart rate may not have indicated it, where as visual inspection of the graphs allowed for training errors to be indicated. Clearly, the goal of training is to remain within the defined threshold for the entire training period. The use of heart rate monitors, on the whole, are better training intensity monitors than the use of ratings of perceived exertion.

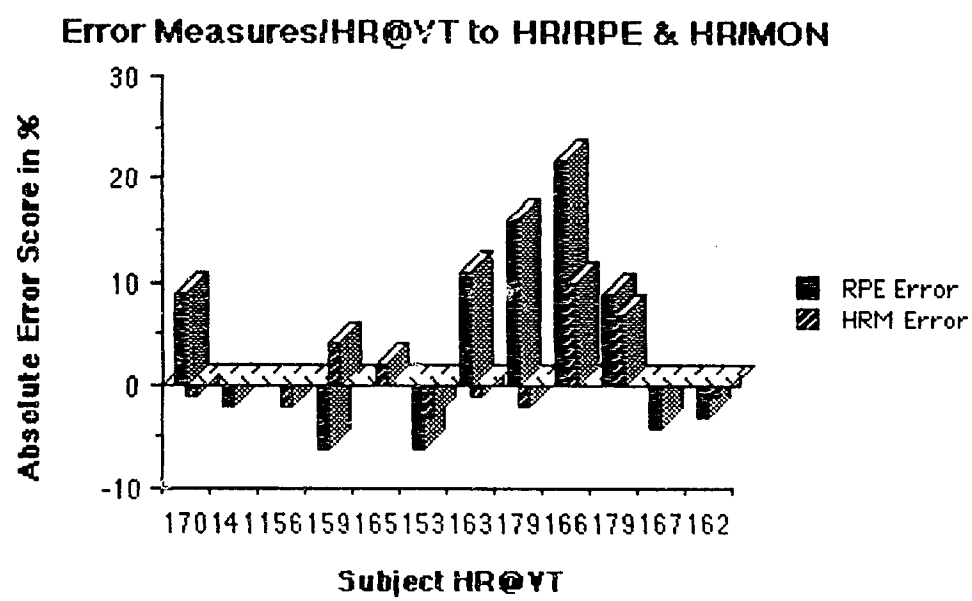

Figure 6. Error measure scores for HR @ RPE and HR @ HR/MON versus HR @ VT.

TABLE 13. Percentage error between HR @ VT and HR @ RPE, and HR @ VT and HR @ HR/MON, in swimming, cycling, and running.

SUBJECT NO.	HR @ VT versus HR @ RPE swim	cycle	run	HR @ VT versus HR @ HR/MON swim	cycle	run
1.	-5.3	+2.9	n/a	+.5		
2.	+1.4	-3.8	-6.5	0		
3.	+3.8	0	+1.2	-2.5		
4.	0	-5.3	-2.9	+1.3		
5.	+2.0	+4.0	-6.6		+2.0	
6.	-3.6	0	-2.8		-1.2	
7.	+5.6	-6.7	-5.1		+.6	
8.	+.6	-8.9	-6.6		+1.1	
9.	+4.8	+1.2	+1.9			+.6
10.	+8.8	+2.5	-5.0			-4.0
11.	+1.9	-9.3	+4.3			+1.8
12.	+3.6	-10.5	-13.3			-6.0

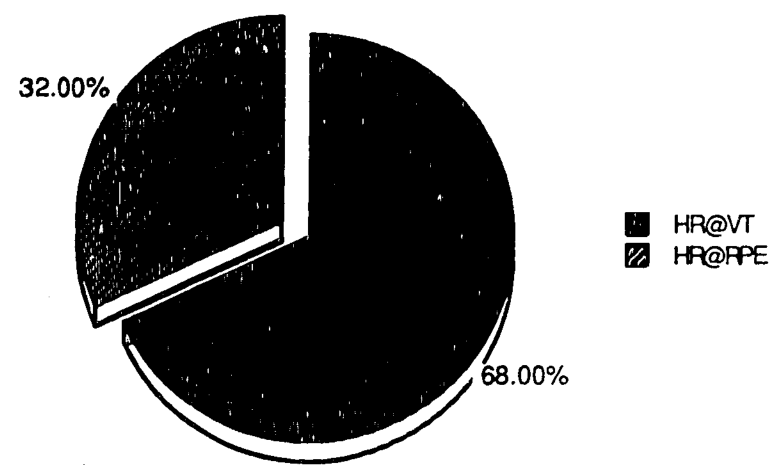

Figure 7a. Percent variation predicted by HR @ RPE.

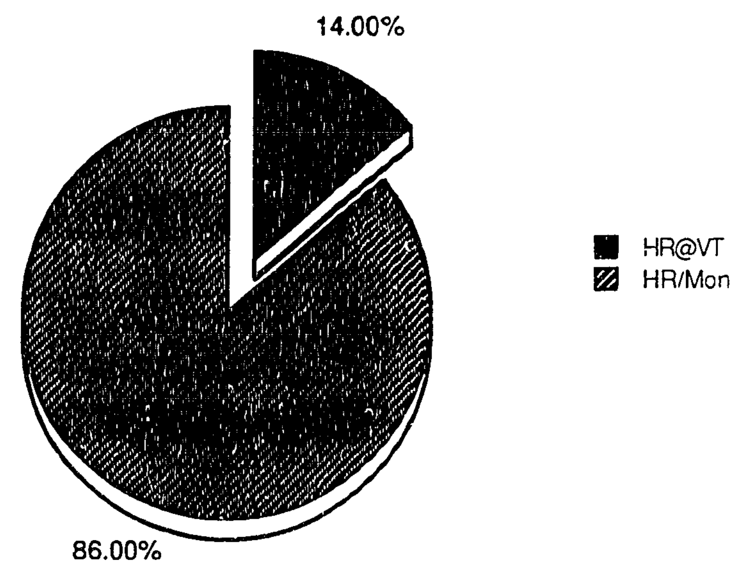

Figure 7b. Percent variation predicted by HR @ HR/MON.

This study, in agreement with the literature, has made individual assessment of the VT and heart rate before assigning training heart rates (Davis & .nvertino, 1975; Davis et al., 1979; Dwyer & Bybee, 1983; Katch et al., 1973). With the use of a HR/MON, a number of triathletes have indicated the ability to train at the heart rate +/- 5 bpm associated with VT in the field.

Those individuals unable to maintain training intensity with the HR/MON would most likely be able to do so with practice.

Applications

The use of daily resting and training heart rate monitoring is advisable for competitive triathletes. Ventilatory threshold training should take place initially the pre-competitive season. Once the competitive season begins this form of continuous ventilatory threshold training should take place three to four times per week in each sport in order to maintain the training effects. Also at this time high quality interval training should take place in each sport. This latter form of training is necessary to recruit fast glycolytic muscle fibres utilized when triathletes need to sprint as well as to transition from one sport to the next. This form of training should take place at least two or three times per week. Interval times would be two to four minutes with the total durayion of training matching the time it normally takes to complete the race portion of the particular sport. For example, if an individual completed a 1.5 km swim in 20 minutes, the total duration of high quality intervals should be at least 20 minutes. For other training it is advisable to consult reference materials dealing with seasonal training requirements.

CHAPTER V

SUMMARY AND RECOMMENDATIONS

Summary

The paucity of descriptive physical and physiological data makes it difficult to compare present day triathletes to other athletes.

As a result of this study, more descriptive and physiological data are available for comparison purposes.

The use of RPE at ventilatory threshold as a training index has been questioned and investigated by many researchers, and the results have been conflicting. Using this method with triathletes in swimming, cycling, and running has provided additional insight into the use of this method. Based upon visual inspection, although only eight out of eleven subjects were able to correctly utilize the HR/MON, only three individuals in 36 tests were able to utilize the RPE at VT.

The results of this study indicate obvious disagreement with the literature. Training at an RPE associated with VT would cause individuals to train at variable intensities possibly reducing the time for effective training. In agreement with Eston et al., (1987), any reliable application of effort ratings in the control of exercise intensity is dependent upon the individuals' abilities to reproduce similar levels of work at equivalent metabolic demand across a range of exercise intensities, on different occasions, and in different sports. Those subjects who had poor HR at RPE performance were favourably affected by the HR/MON protocol.

As a result of this study, a few general concluding statements can be put forth:

1) The ability to train at an RPE associated with VT in sports is difficult for the neophyte, as well as well-trained athlete regardless of sport background.

2) The use of a heart rate monitor in order to quantify training is a more viable method than RPE, and is recommended.

3) Discontinance of the use of HR/MON may be possible with the athlete's ability to relate the correct HR to the perceived exertion of exercise.

Recommendations

The following recommendations are an outcome of the present study, and by no means make up a comprehensive list. A study involving heart rate monitor field measurements in each sport would contribute further to the literature.

A training study utilizing the methods and conclusions of this study is recommended.

Since triathletes are beginning to be regarded as single-sport athletes the development of a maximal oxygen uptake and ventilatory threshold protocol involving all three sports would be useful.

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Appendix A.

UNIVERSITY OF ALBERTA

TRIATHLETE VENTILATORY THRESHOLD & MAXIMAL OXYGEN POWER STUDY

I,______________________________ AUTHORIZE JANE KELLOCK AND ASSOCIATES , OF THE DEPT. OF PHYSICAL EDUCATION AND SPORT STUDIES & THE DEPT. OF ATHLETIC SERVICES TO ADMINISTER A SERIES OF TESTS AS PART OF A STUDY . I UNDERSTAND THAT I MAY VOLUNTARILY DISCONTINUE A TEST WITHOUT PREJUDICE, IF AT ANY TIME I EXPERIENCE ANY UNSUAL DISCOMFORT. I UNDERSTAND THAT THE STAFF ADMINISTERING THE TESTS ARE WELL QUALIFIED AND WILL ASK ME TO DISCONTINUE A TEST IF ANY INDICATIONS OF ABNORMAL RESPONSE TO THE TEST BECOME APPARENT. I UNDERSTAND THAT I WILL VOLUNTARILY PERFORM THE TESTS AS EXPLAINED TO ME AND I HAVE THE OPPORTUNITY TO QUESTION AND DISCUSS THE EXACT PROCEDURE THAT WILL BE FOLLOWED. THE STUDY WILL REQUIRE THAT :

1. SUBJECT MAINTAIN A COMPLETE TRAINING DIARY AS OUTLINED BY THE STUDY.
2. SUBJECT WILL DRESS APPROPRIATELY FOR THE TESTING SESSIONS I.E. SWIMSUIT, SHORTS, T-SHIRT, CYCLING SHOES AND TRAINING SHOES.
3. SUBJECT NOT EAT OR PERFORM STRENOUS EXERCISE FOR A PERIOD OF 1.5 HOURS PRIOR TO ANY TESTING.

ALL TESTS WILL BE ADMINISTERED IN THE SWIMMING POOL , ON A BICYCLE ERGOMETER AND TREADMILL, AND DURING MY OWN TRAINING SESSIONS.

I ACKNOWLEDGE THAT I HAVE READ THIS FORM AND I UNDERSTAND THE TESTING PROCEDURES TO BE PERFORMED AND THE INHERENT RISKS AND BENEFITS, AND I CONSENT TO VOLUNTARILY PARTICIPATE. I UNDERSTAND THAT THE DATA OBTAINED FROM THE TESTING WILL REMAIN ANONYMOUS AND WILL BE USED AS EXPERIMENTAL DATA FOR RESEARCH AND POSSIBLE PUBLICATION AND IT MAY BE VIEWED BY THE TEST ADMINISTRATORS, MYSELF AND ANY SIGNIFICANT OTHERS INVOLVED IN THIS STUDY. I KNOW NO REASON I SHOULD NOT PARTICIPATE IN THIS STUDY.

DATE SIGNATURE

WITNESS

Appendix B

TRAINING LOG

DATE: WEATHER:

WEIGHT (kg.): RESTING HEART RATE:

HOURS OF SLEEP: OF WORK/STUDY:

INJURIES:

FEELINGS - PRE-TRAINING:

POST-TRAINING:

DESCRIPTION OF TRAINING

SWIMMING:
TIME OF DAY:
POOL LENGTH: TRAINING HEART RATE:

TYPE:

TOTAL DISTANCE:
TOTAL TIME:

CYCLING:
TIME OF DAY: TRAINING HEART RATE:
WINDTRAINER/ ERGOMETER/OUTDOORS:
TYPE:

TOTAL DISTANCE:
TOTAL TIME:

RUNNING:
TIME OF DAY: TRAINING HEART RATE:
LOCATION:
TYPE:

TOTAL DISTANCE:
TOTAL TIME:

NUTRITION

BREAKFAST	***LUNCH***	***SUPPER***
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SNACKS:

TOTAL CALORIES: ___________

Appendix C Calculation of Body Fat

According to Archimides' principle, a body is buoyed by a force equal to the weight of the water displaced. Therefore, the detemination of body density via hydrostatic weighing is inaccordance to the formula:

$$Db = (Ma \text{ X } Dw/ (Ma - Mw)$$

where: Db = density of the body

M_a = weight of the subject in air

Mw = weight of the subject in water

Dw = density of the body in water

The weight in the water was calculated by the formula:

[(weight belt X chart recording) / recorder unit range) - weight belt]

The total volume of gas was calculated as the sum of the vital capacity, residual volume, and gastro-intestinal tract gas.

$$TVG= VC + RV + GI = TVG \text{ X } .0362$$

where: TVG = total volume of gas

capacity (Comroe, 1968)

GI = gastrointestinal gas, assumed to be 7.01 cubic inches

0.362 = the weight supported by one cubic inch of air at BTPS.

The formula then becomes

$$Db = Mw/ [(Ma -Mw/Dw) + TVG$$

Total lung volume was multiplied by 61.02 in order to convert it to cubic inches.

The formula of Brozek et al, (1963) was used to estimate percent body fat from body density.

% body fat = [(4.570/body density) - 4.142] x 100]

The estimate of percent body fat from skinfolds was based upon the sum of four sites: tricep, bicep, subscapular and suprailiac (Durnin & Wormesley, 1974).

Appendix D.

RPE SCALE (BORG,1982)

SCORE	SUBJECTIVE RATING
6	
7	Very very light
8	
9	Very light
10	
11	Fairly light
12	
13	Somewhat hard
14	
15	Hard
16	
17	Very hard
18	
19	Very very hard
20	

Appendix E.

Correlation Matrix for Variables: X_1 ... X_{35}

	VO2/l/s...	VO2/l/c...	VO2/l/ ...	VO2/ml...	VO2/ml...	VO2/ml...	RPE swim	RPE cycle
VO2/l/s...	1							
VO2/l/c...	.313	1						
VO2/l/ run	.562	.202	1					
VO2/mls ...	.501	.347	.301	1				
VO2/mls ...	-.302	.61	-.098	.488	1			
VO2/mls ...	.193	.602	.226	.508	.607	1		
RPE swim	.093	.014	.62	-.253	-.215	-.389	1	
RPE cycle	.043	-.612	.278	.194	-.284	-.106	-.111	1
RPE run	-.255	-.479	-.586	-.306	-.258	-.476	-.111	-.111
HR@VO...	.551	.15	.228	.055	-.411	.188	-.139	.06
HR@VO...	.704	.461	.312	.031	-.294	.011	.098	-.306
HR@VO...	.823	.029	.353	.211	-.554	-.289	.192	.152
vt/l/swim	.833	.167	.557	.139	-.507	.088	.125	.028
vt/l/cycle	-.217	.77	-.023	.012	.706	.469	.082	-.744
vt/l/run	.304	-.023	.728	.038	-.27	-.188	.647	.404
vt/mls/s...	.693	.214	.59	.623	-.024	.221	.045	.164

Correlation Matrix for Variables: X_1 ... X_{35}

	VO2/l/s...	VO2/l/c...	VO2/l/ ...	VO2/ml...	VO2/ml...	VO2/ml...	RPE swim	RPE cycle
vt/mls/c...	-.471	.552	-.152	.206	.922	.484	-.076	-.468
vt/mls/r...	.206	.342	.47	.352	.265	.538	.059	.278
RPE swi...	.482	.411	.347	.282	.03	.083	.124	-.307
RPE cycl...	-.311	.277	.001	-.147	.287	-.123	.421	-.57
RPE run (...	-.013	.012	.271	-.317	-.25	-.067	.059	.297
R swim (...	.054	-.035	.424	-.373	-.285	-.279	.459	.084
R cycle (...	-.283	-.482	-.051	.013	-.04	-.584	.243	.451
R run (vt)	.439	.01	.168	.151	-.327	-.305	.12	.23
HR swim ...	.601	-.076	.643	.152	-.494	.104	.167	.367
HR cycle ...	.119	.225	.265	-.172	-.11	-.363	.691	-.566
HR run (vt)	.467	-.015	.383	.056	-.426	-.408	.398	.262
VE-swim	.581	.088	.471	.593	.014	.651	-.322	.396
VE-cycle	.564	.505	.468	.521	.292	.719	-.096	-.092
VE-run	.705	.077	.735	.369	-.214	.229	.405	.147
R-swim	-.544	.036	-.314	-.337	.305	-.203	.323	-.462
R-cycle	-.048	.106	.112	.159	.249	-.386	.434	-.122

Correlation Matrix for Variables: X_1 ... X_{35}

	VO2/l/s...	VO2/l/c...	VO2/l/ ...	VO2/ml...	VO2/ml...	VO2/ml...	RPE swim	RPE cycle
R-run	.448	-.09	-.236	.078	-.406	-.147	-.519	.13
%BF-C	-.241	-.397	-.223	-.322	-.313	-.432	.263	.019
%BF-H	-.056	-.264	.076	-.325	-.396	-.415	.49	-.001

Correlation Matrix for Variables: X_1 ... X_{35}

	RPE run	HR@VO...	HR@VO...	HR@VO...	vt/l/sw...	vt/l/cy...	vt/l/run	vt/mls/...
RPE run	1							
HR@VO...	-.487	1						
HR@VO...	-.248	.42	1					
HR@VO...	.035	.481	.665	1				
vt/l/swim	-.367	.571	.82	.642	1			
vt/l/cycle	-.287	-.293	.141	-.508	-.14	1		
vt/l/run	-.504	.391	.123	.447	.239	-.327	1	
vt/mls/s...	-.508	.23	.539	.396	.742	-.002	.18	1

Correlation Matrix for Variables: X_1 ... X_{35}

	RPE run	HR@VO...	HR@VO...	HR@VO...	vt/l/sw...	vt/l/cy...	vt/l/run	vt/mls/...
vt/mls/c...	-.181	-.545	-.279	-.725	-.505	.863	-.387	-.098
vt/mls/r...	-.649	.514	-.149	.054	-.021	-.029	.609	.005
RPE swi...	-.36	.21	.745	.381	.596	.276	.113	.704
RPE cycl...	-.322	-.065	-.095	-.395	-.178	.563	.076	.004
RPE run (...	-.654	.399	.343	.04	.364	-.033	.429	.208
R swim (...	-.197	-.219	.477	.098	.442	.143	.22	.328
R cycle (...	.312	-.646	-.38	-.048	-.337	-.302	.08	-.032
R run (vt)	-.098	.537	.331	.774	.195	-.514	.631	.058
HR swim ...	-.632	.788	.375	.449	.743	-.382	.601	.588
HR cycle ...	-.182	.037	.32	.118	.244	.349	.259	.242
HR run (vt)	-.215	.513	.361	.782	.297	-.492	.813	.135
VE-swim	-.301	.369	.208	.266	.488	-.221	.084	.552
VE-cycle	-.176	-.028	.38	.141	.454	.325	-.17	.503
VE-run	-.005	.117	.291	.52	.522	-.192	.345	.44
R-swim	.497	-.743	-.425	-.504	-.592	.452	-.365	-.543
R-cycle	.156	-.705	.079	.035	-.11	.264	-.009	.243

Correlation Matrix for Variables: X_1 ... X_{35}

	RPE run	HR@VO...	HR@VO...	HR@VO...	vt/l/sw...	vt/l/cy...	vt/l/run	vt/mls/...
R-run	.202	.266	.627	.571	.519	-.354	-.274	.339
%BF-C	.298	.15	-.532	-.023	-.396	-.38	.227	-.582
%BF-H	.01	.326	-.311	.101	-.133	-.312	.478	-.365

Correlation Matrix for Variables: X_1 ... X_{35}

	vt/mls/...	vt/mls/...	RPE swi...	RPE cycl...	RPE run ...	R swim ...	R cycle ...	R run (vt)
vt/mls/c...	1							
vt/mls/r...	.022	1						
RPE swi...	.059	-.164	1					
RPE cycl...	.48	-.043	.239	1				
RPE run (...	-.203	.213	.21	.066	1			
R swim (...	-.076	-.352	.368	.03	.591	1		
R cycle (...	-.037	-.335	-.348	-.062	-.071	.257	1	
R run (vt)	-.568	.369	.226	-.212	.158	-.179	-.079	1
HR swim ...	-.57	.431	.336	-.027	.523	.168	-.333	.352
HR cycle ...	.094	-.221	.5	.813	.037	.292	-.039	.035
HR run (vt)	-.607	.379	.219	-.083	.29	.044	.046	.94
VE-swim	-.183	.387	.277	-.554	-.023	-.116	-.416	.081
VE-cycle	.22	.137	.313	-.369	-.224	.121	-.326	-.269
VE-run	-.298	.201	.233	-.353	-.313	.109	-.137	.142
R-swim	.508	-.375	-.444	.352	-.49	.005	.384	-.547
R-cycle	.325	-.451	.203	.259	-.161	.439	.719	-.141

Correlation Matrix for Variables: X_1 ... X_{35}

	vt/mls/...	vt/mls/...	RPE swi...	RPE cycl...	RPE run ...	R swim ...	R cycle ...	R run (vt)
R-run	-.487	-.402	.383	-.573	.178	.169	-.095	.314
%BF-C	-.315	.172	-.646	.224	-.273	-.496	.164	.203
%BF-H	-.374	.291	-.447	.363	-.037	-.279	.082	.273

Correlation Matrix for Variables: X_1 ... X_{35}

	HR swim...	HR cycle...	HR run (...	VE-swim	VE-cycle	VE-run	R-swim	R-cycle
HR swim ...	1							
HR cycle ...	.17	1						
HR run (vt)	.473	.223	1					
VE-swim	.512	-.447	-.015	1				
VE-cycle	.095	-.208	-.293	.714	1			
VE-run	.378	.055	.221	.627	.683	1		
R-swim	-.77	.229	-.467	-.668	-.122	-.174	1	
R-cycle	-.423	.399	-.006	-.428	.024	.02	.495	1

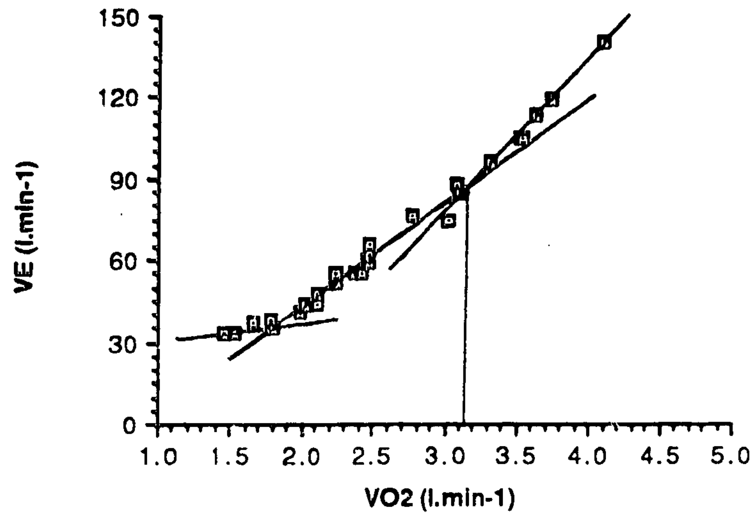
Correlation Matrix for Variables: X_1 ... X_{35}

	HR swim...	HR cycle...	HR run (...	VE-swim	VE-cycle	VE-run	R-swim	R-cycle
R-run	.14	-.289	.167	.289	.15	-.004	-.541	-.081
%BF-C	-.022	.149	.258	-.47	-.636	-.139	.318	-.214
%BF-H	.254	.375	.422	-.428	-.575	-.02	.187	-.184

Correlation Matrix for Variables: X_1 ... X_{35}

	R-run	%BF-C	%BF-H
R-run	1		
%BF-C	-.462	1	
%BF-H	-.504	.926	1

Appendix F.



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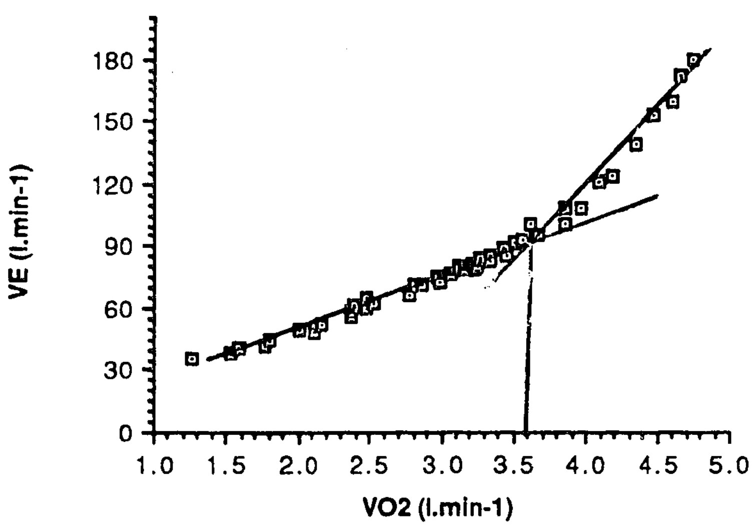

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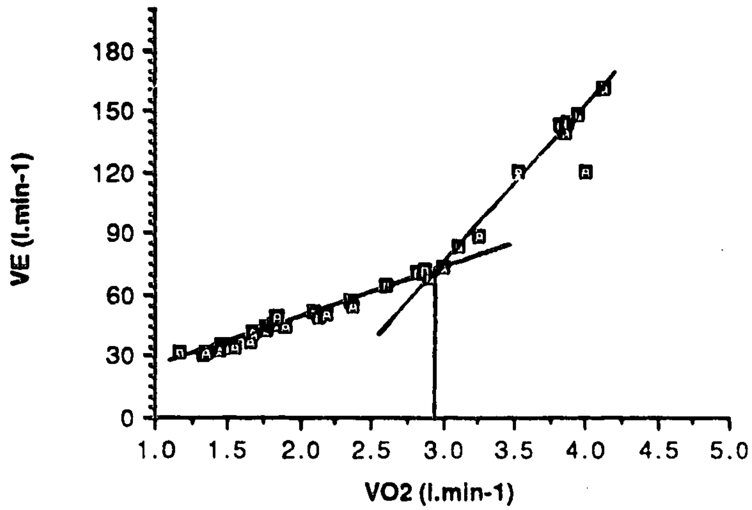
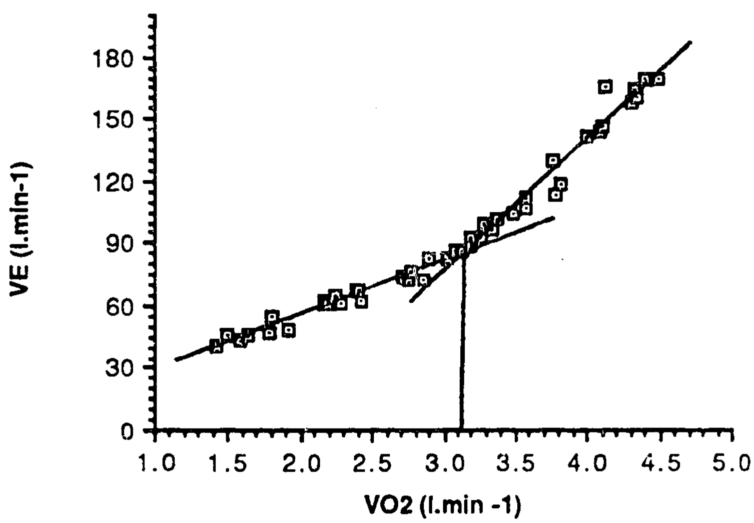


Subject #2 TS Ventilatory Threshold.



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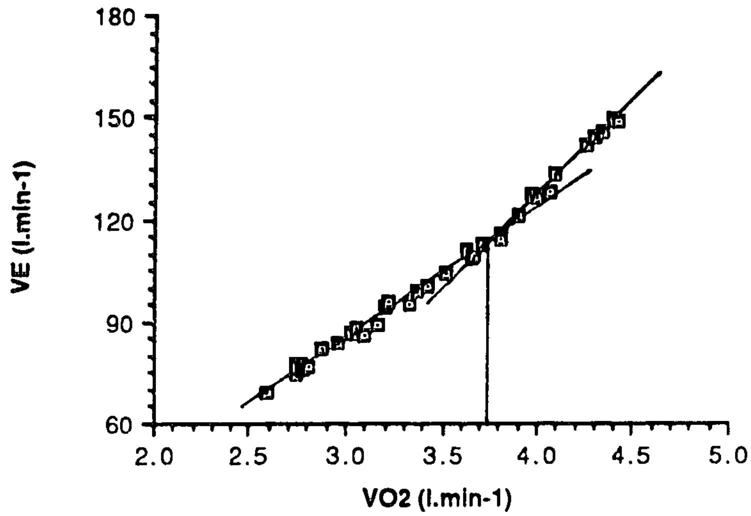
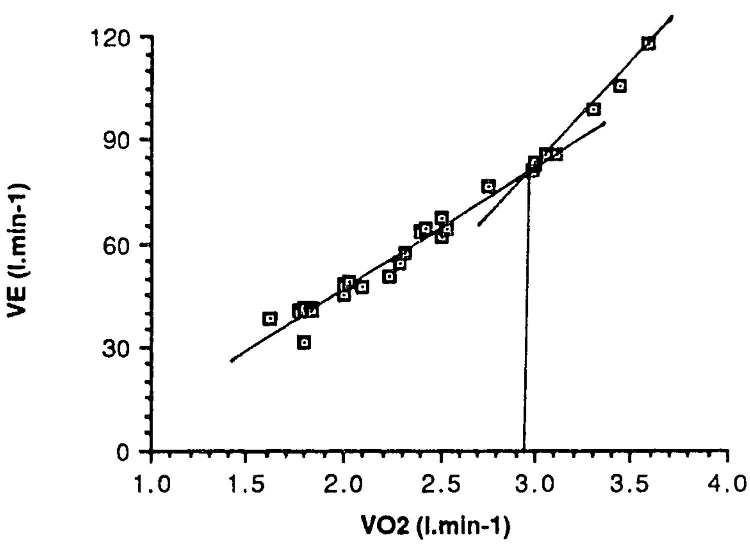
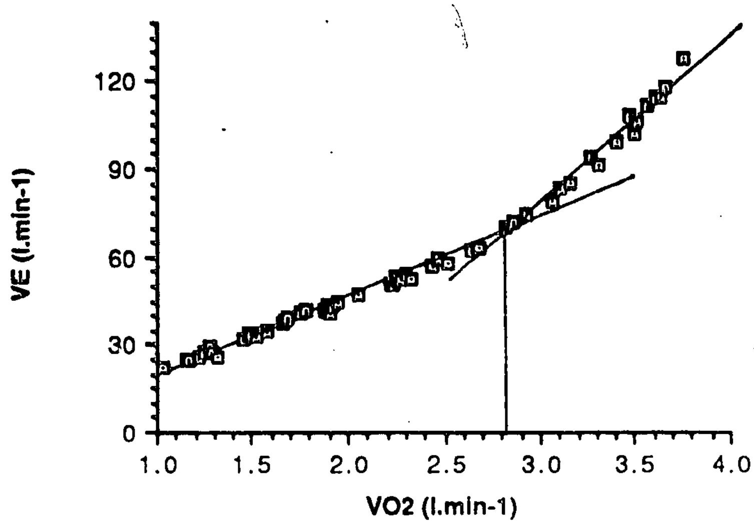


Subject #2 TR Ventilatory Threshold.



Subject #3 TS Ventilatory Threshold.



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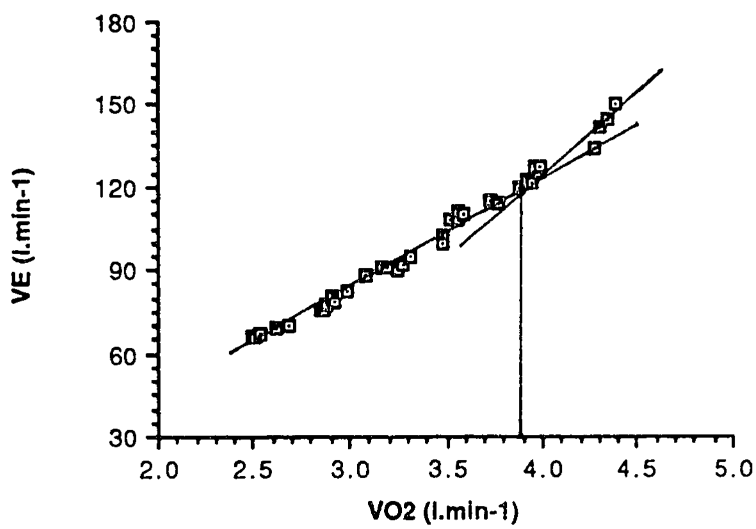

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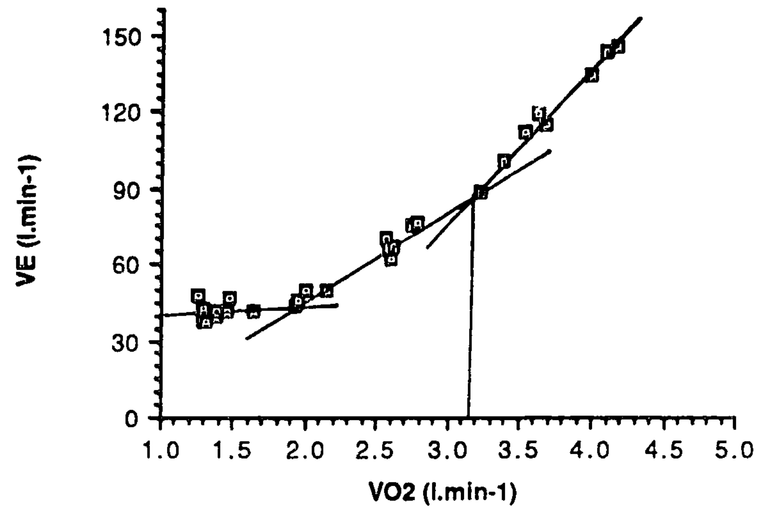
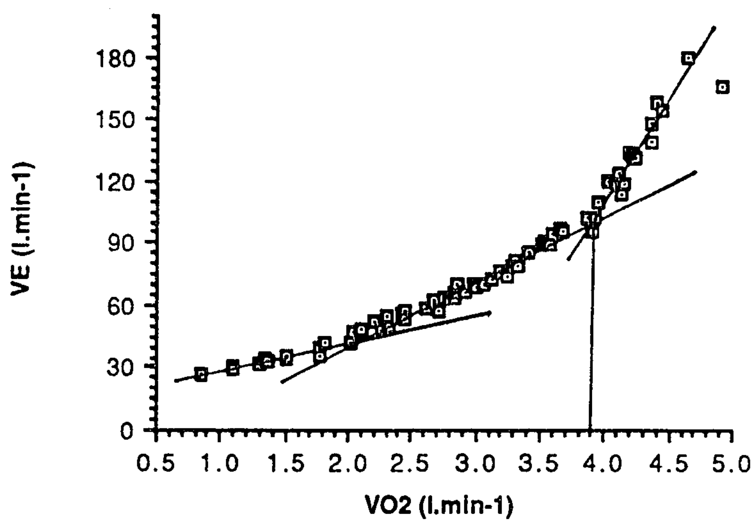


Subject #4 TS Ventilatory Threshold.



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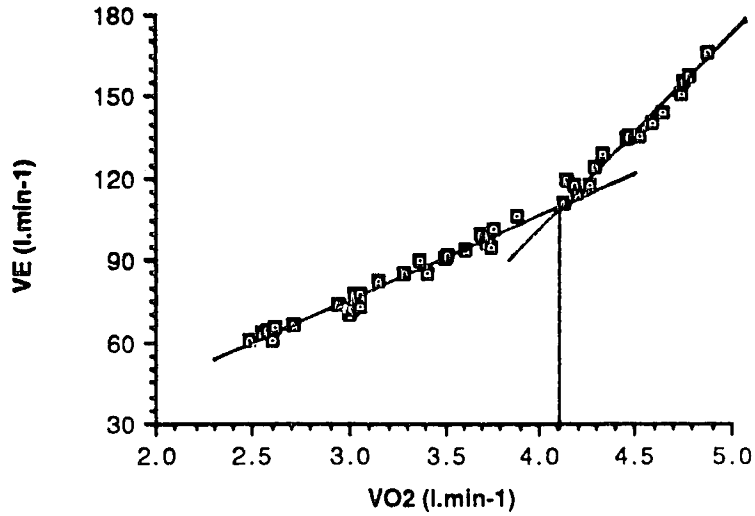
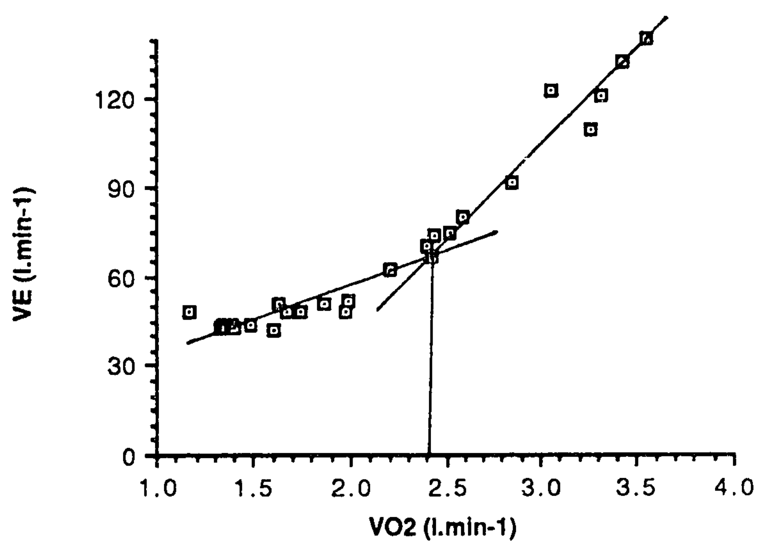


Subject #4 TR Ventilatory Threshold.



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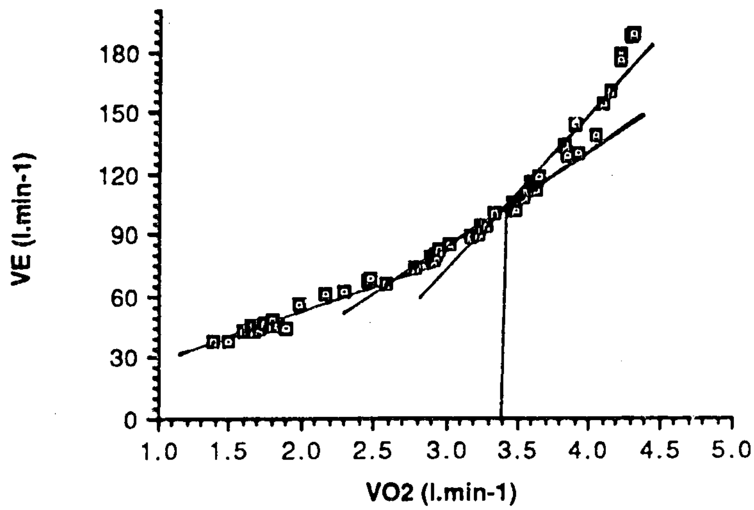

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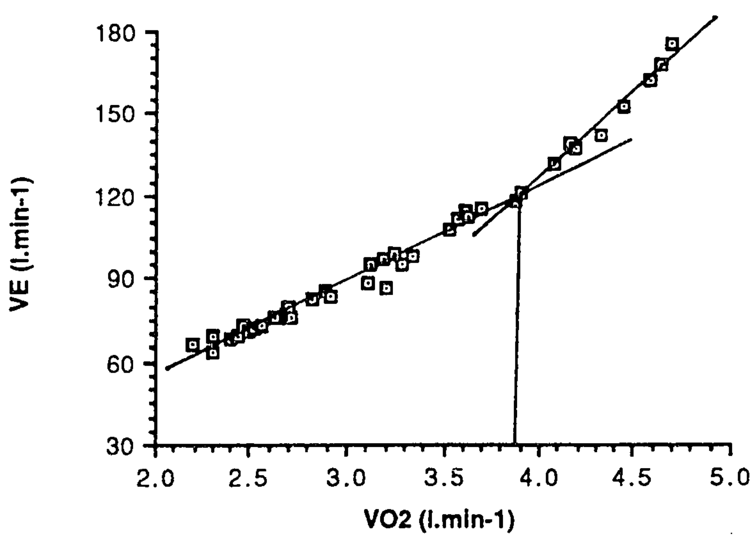

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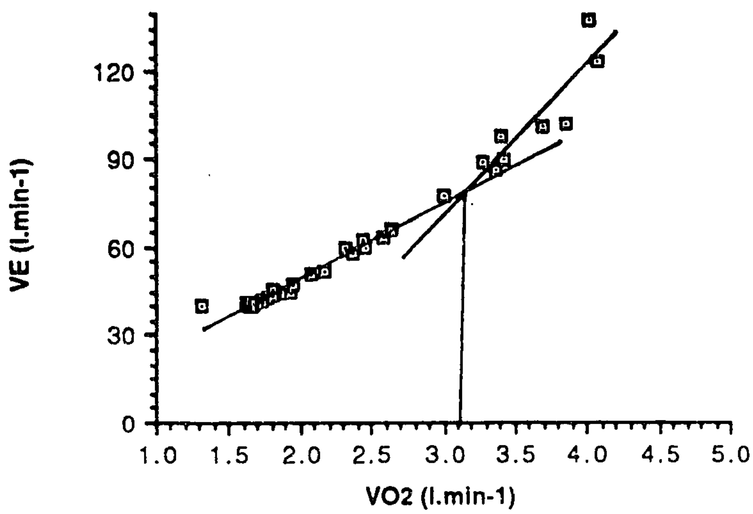

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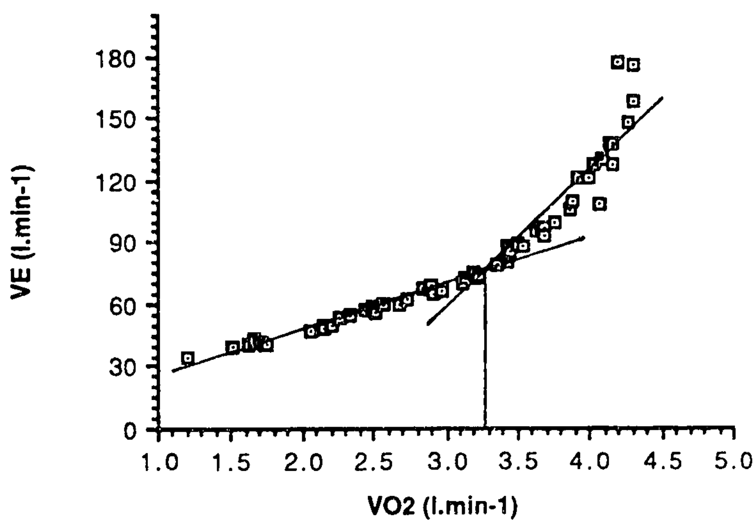

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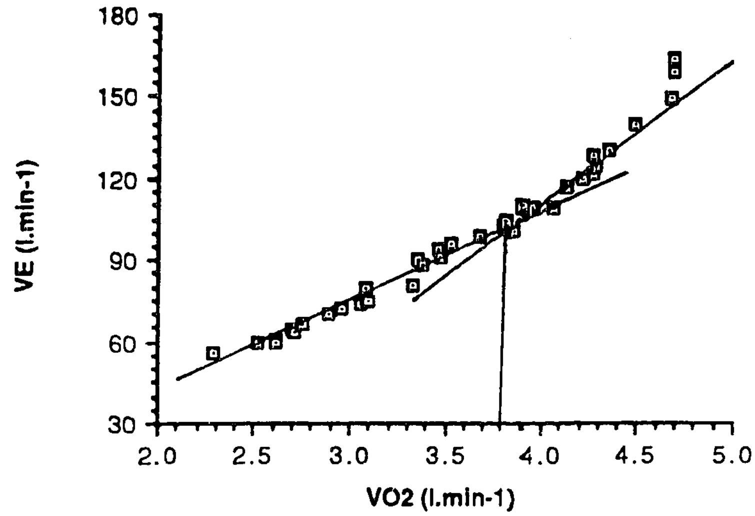
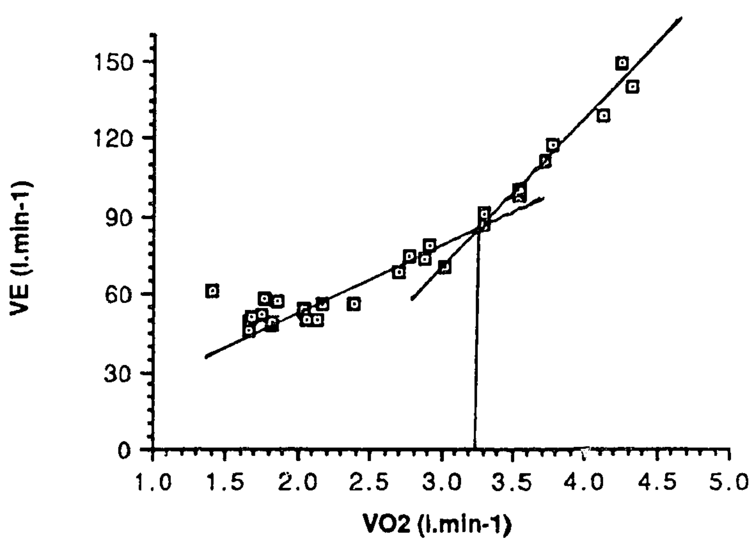
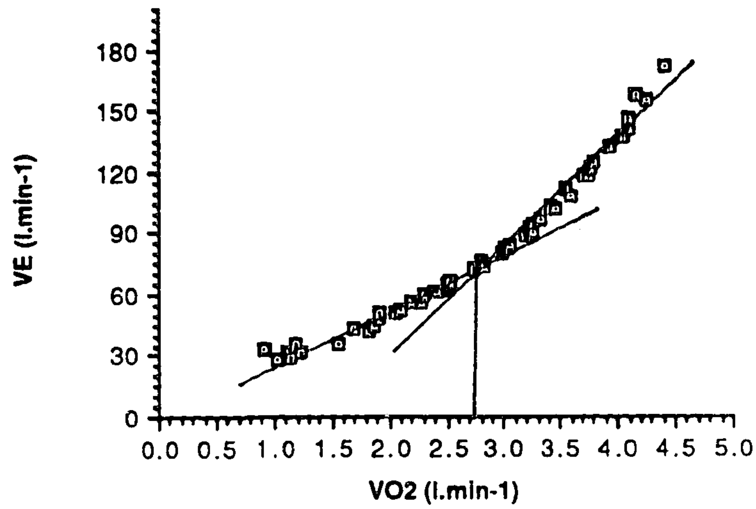


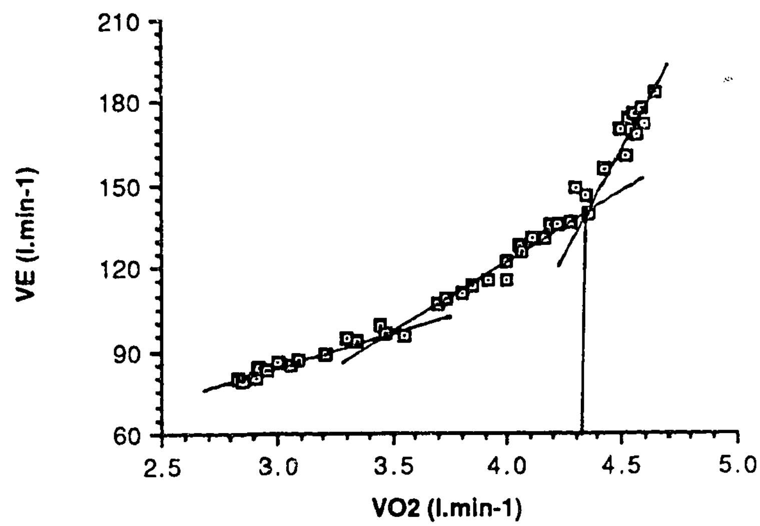
Subject #6 TR Ventilatory Threshold.



Subject #7 TS Ventilatory Threshold.



Subject #7 CE Ventilatory Threshold.



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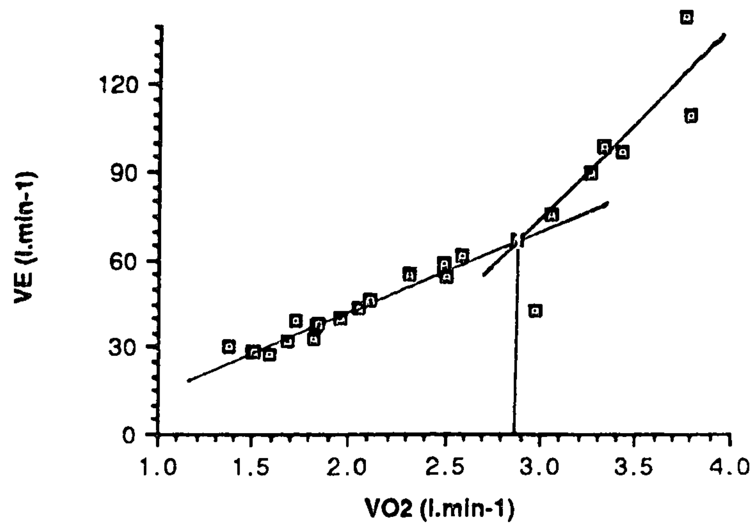

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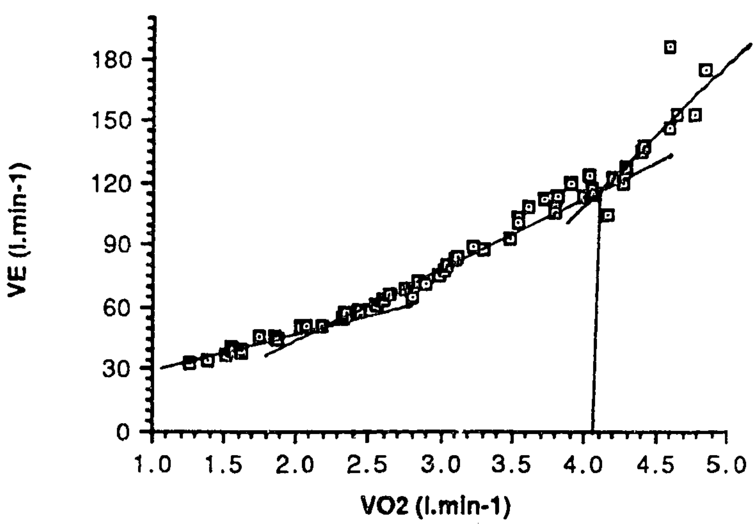

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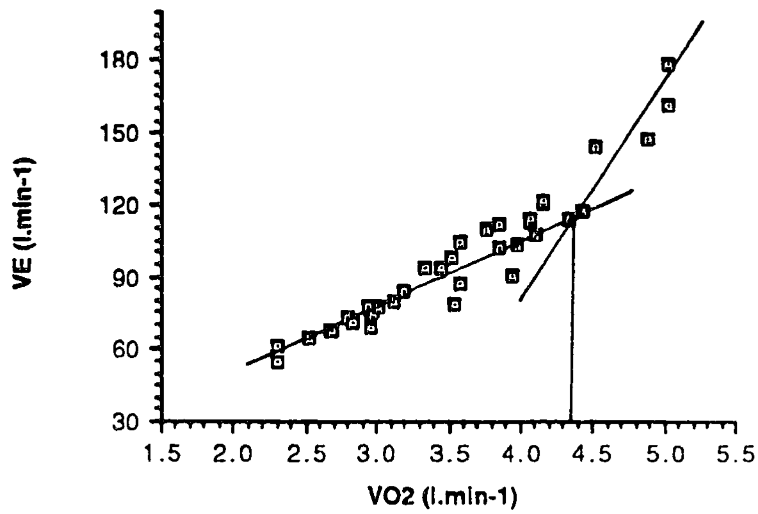

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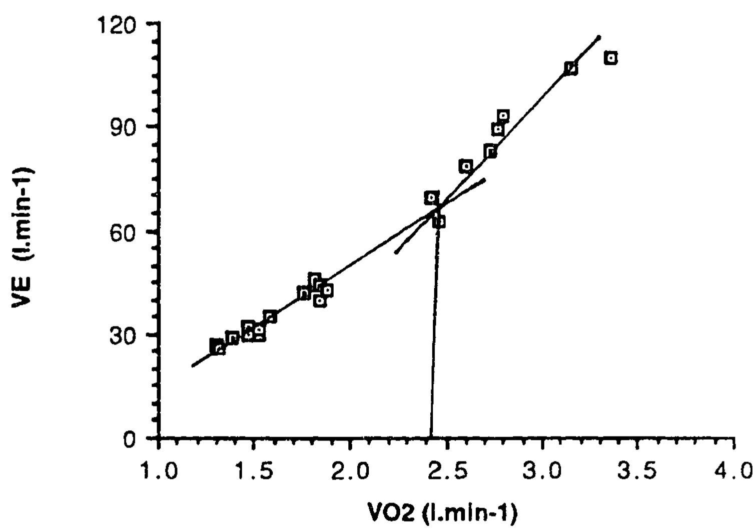

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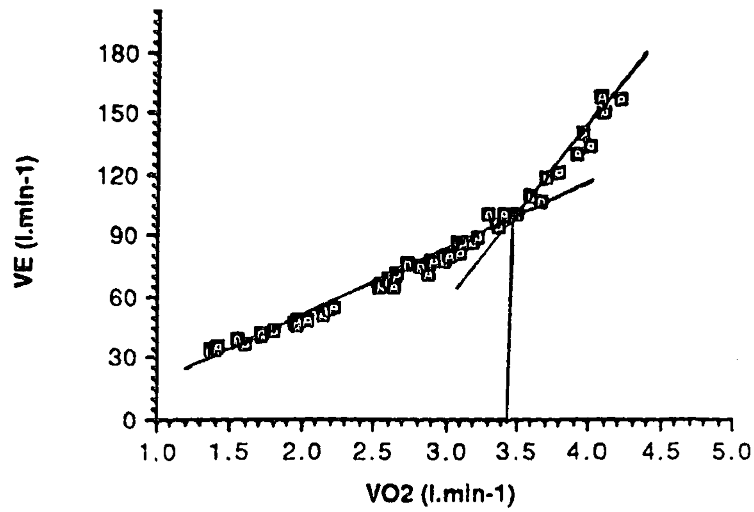

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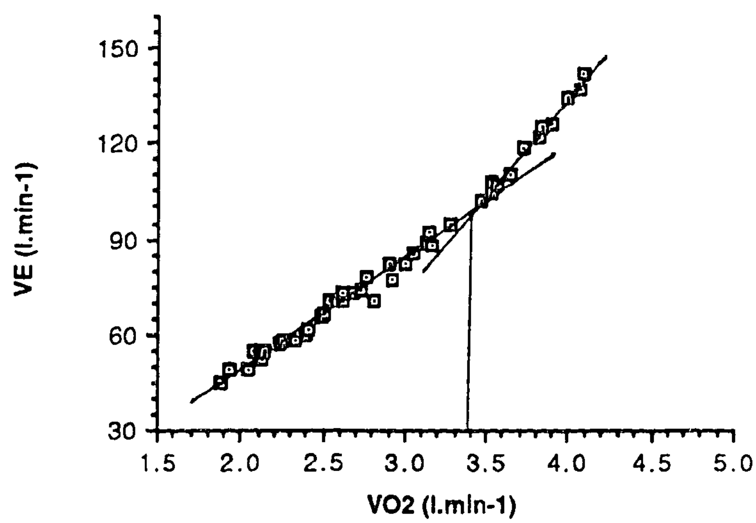

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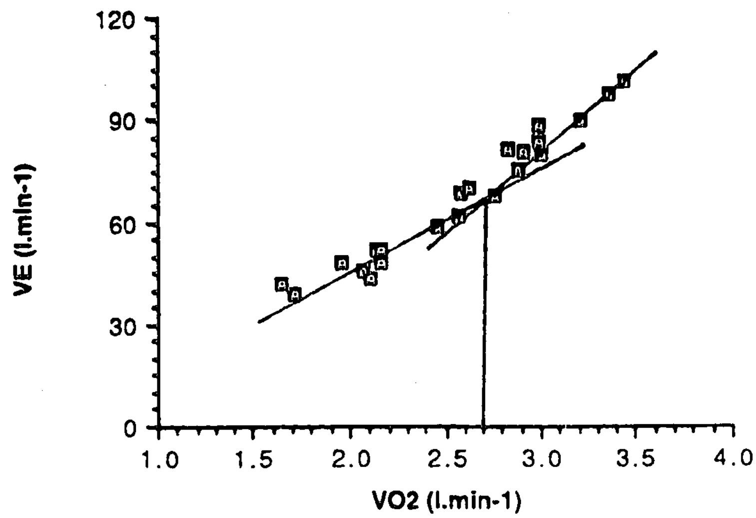

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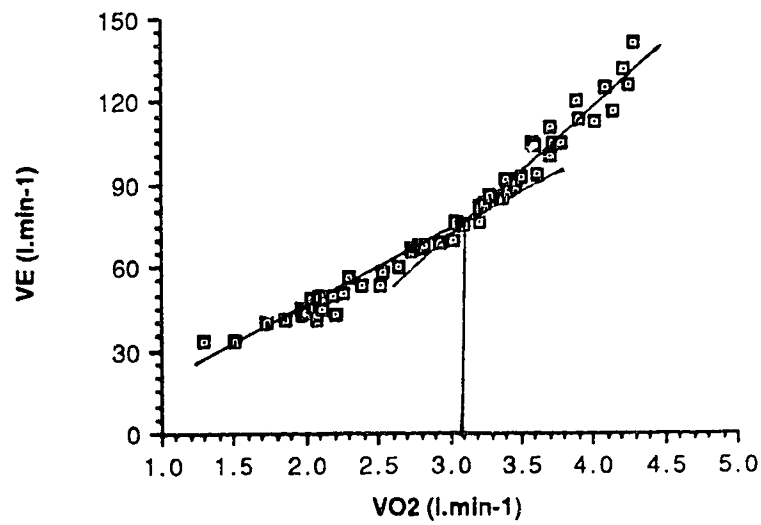

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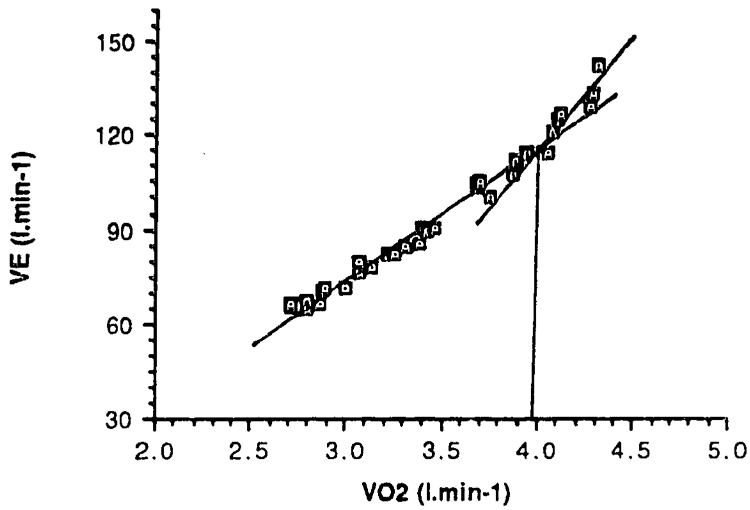

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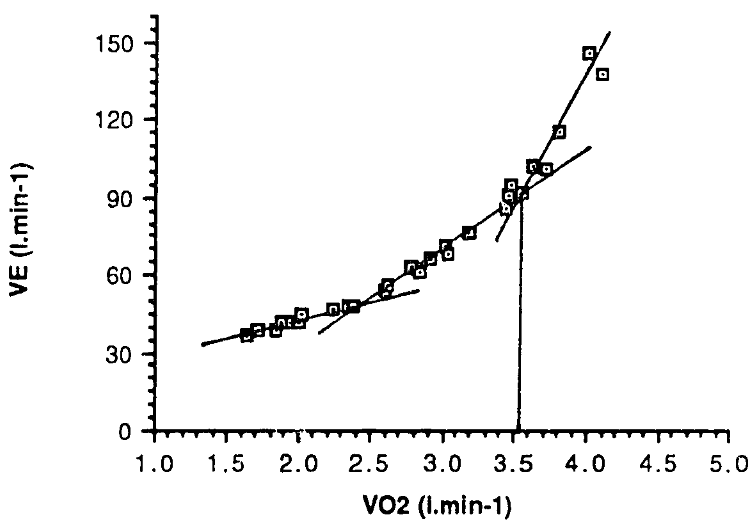

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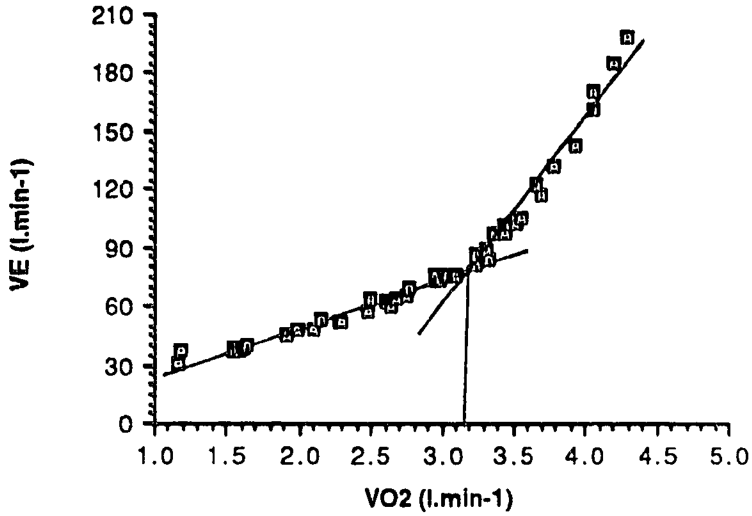

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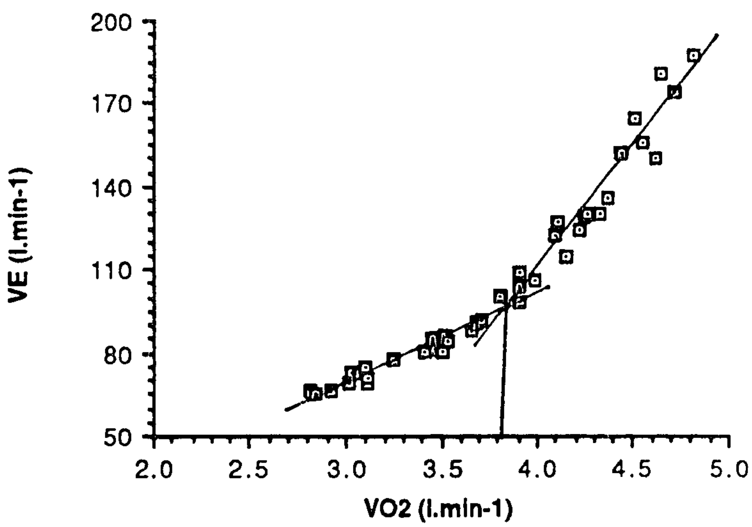

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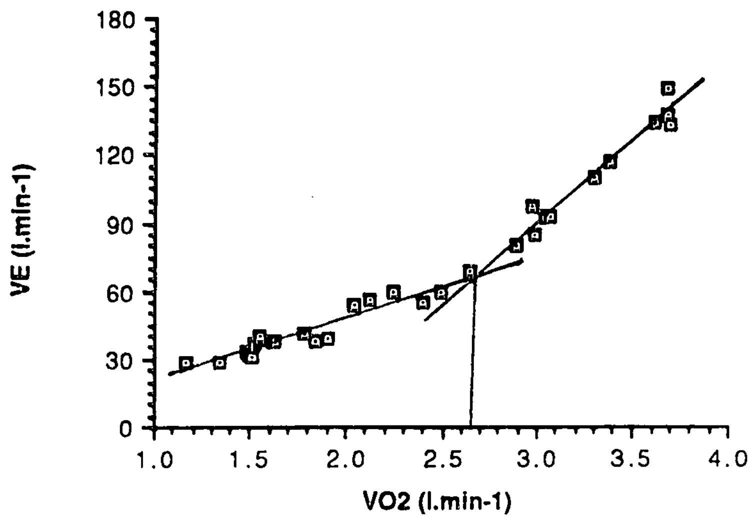

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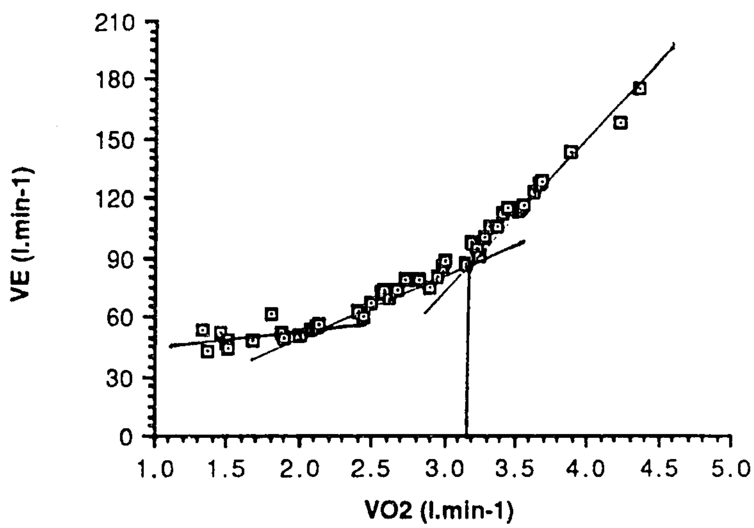

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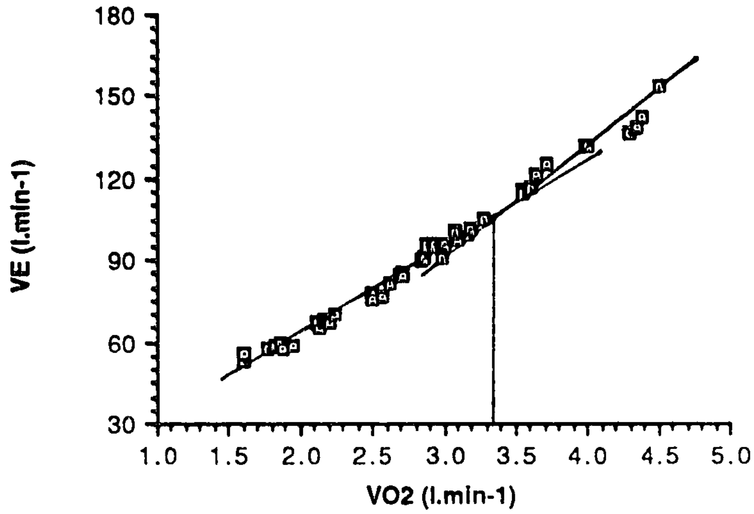
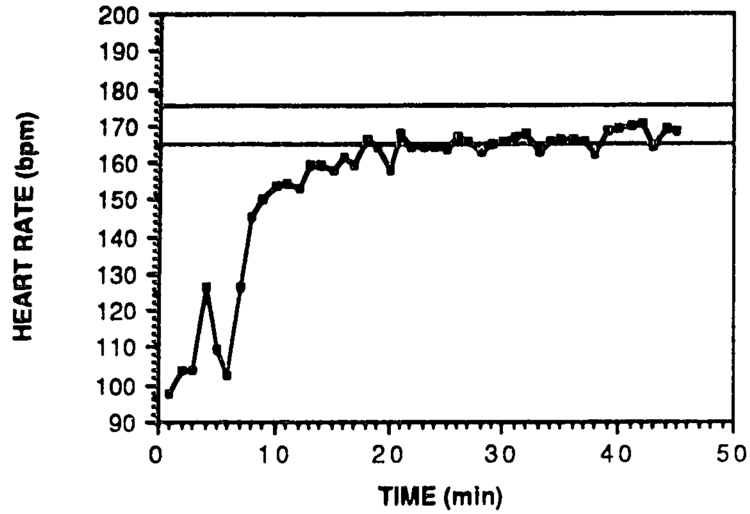
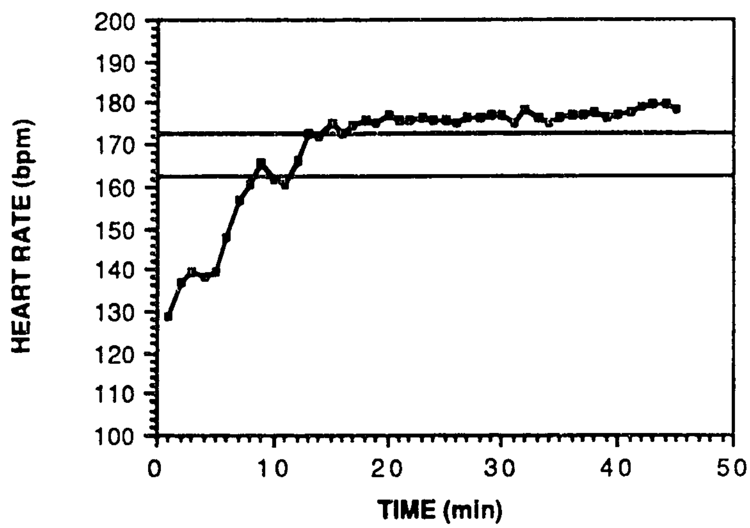


Subject #12 TR Ventilatory Threshold.

Appendix G



TS RPE-17.5 heart rate data points of Subject 1.



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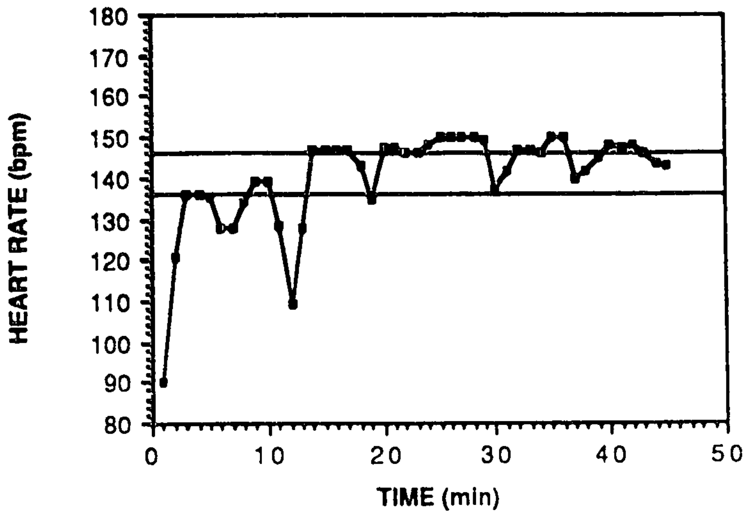

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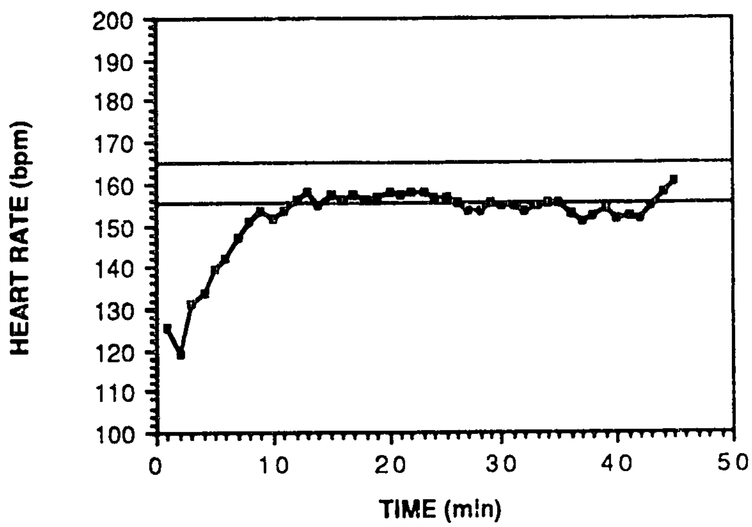

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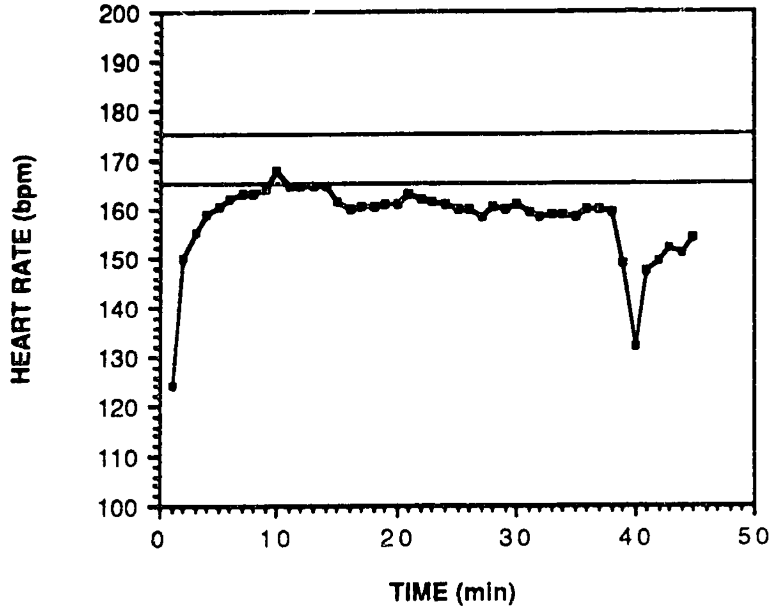

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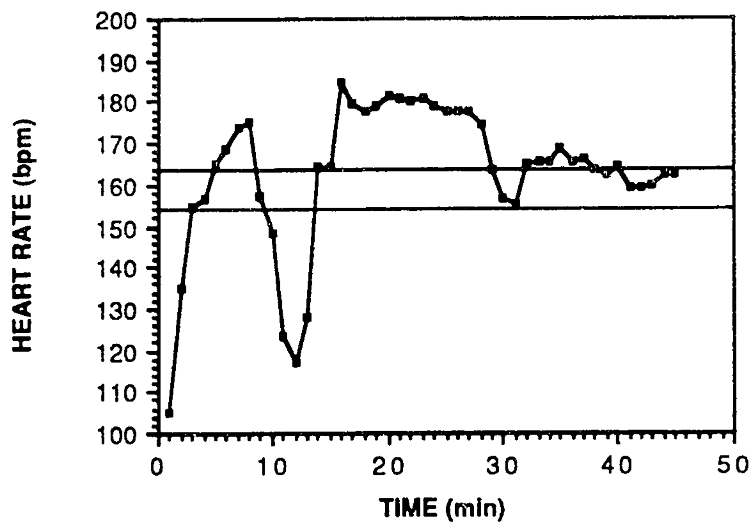
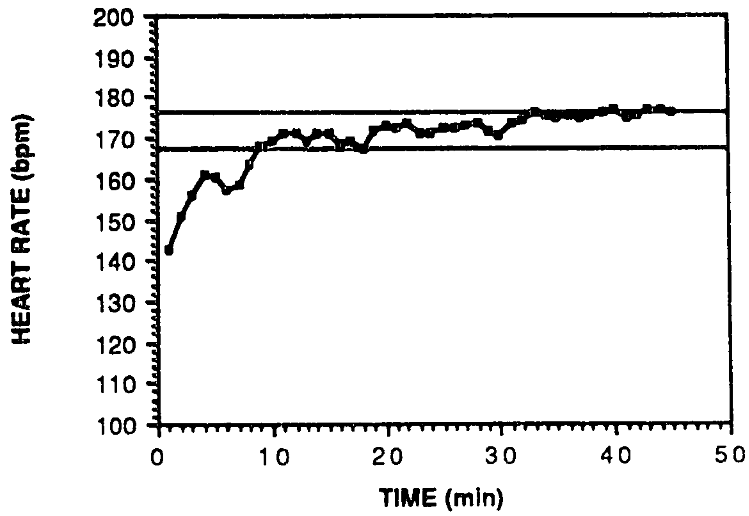


TS RPE-14 heart rate data points of Subject 3.



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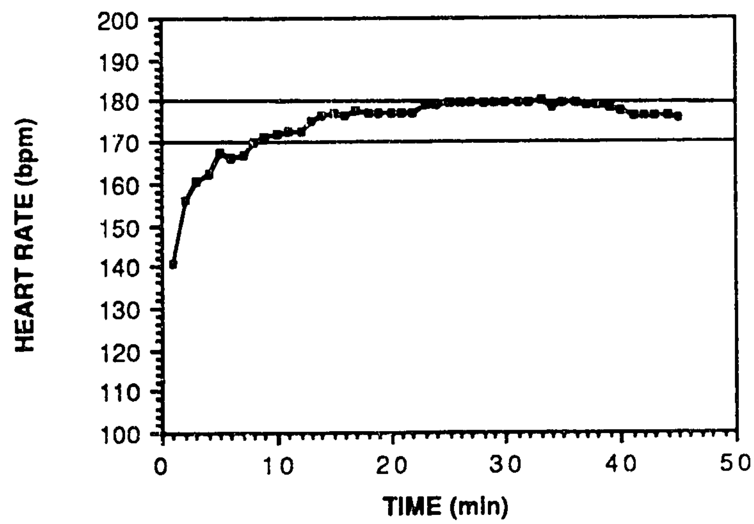

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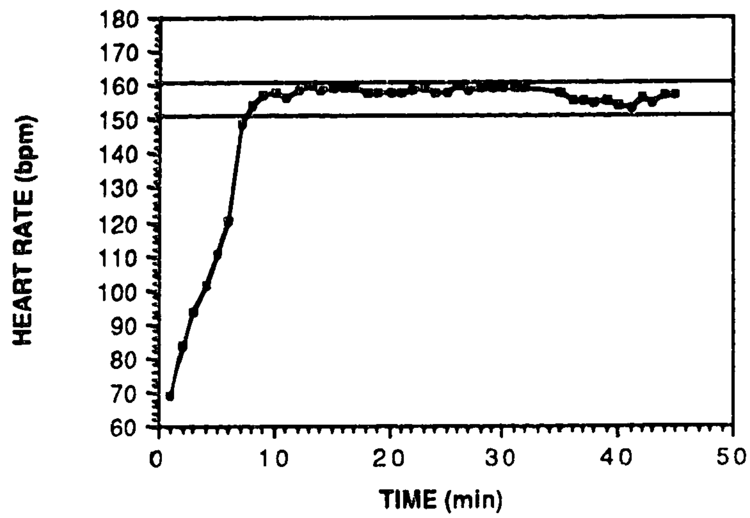

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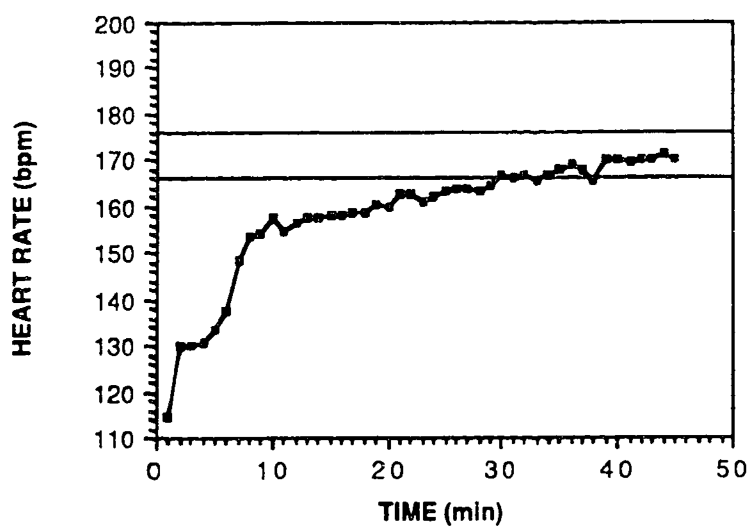

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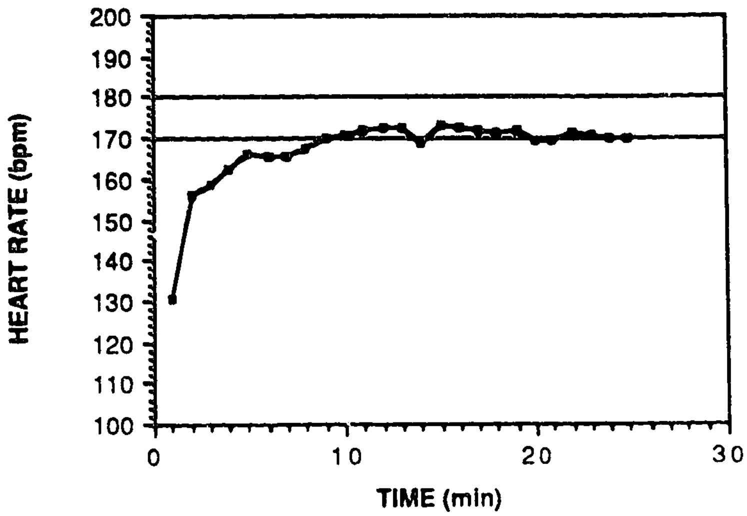

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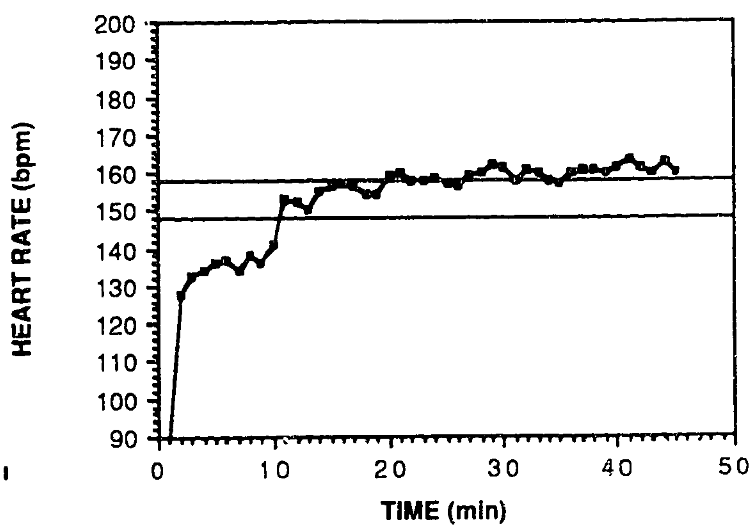

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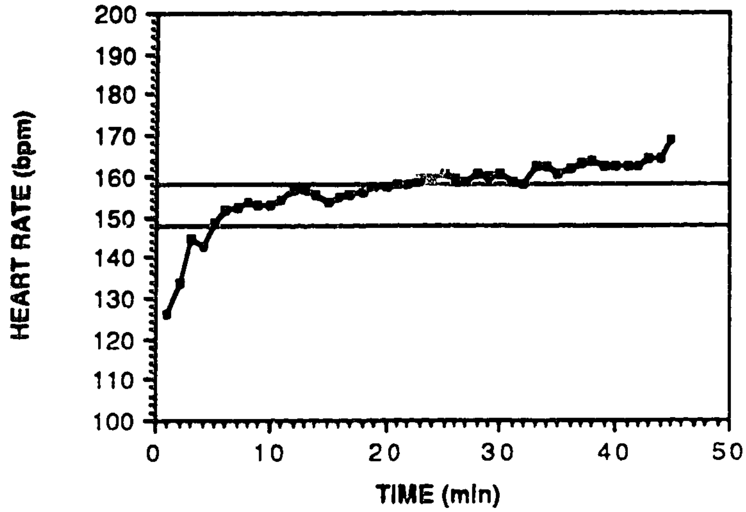

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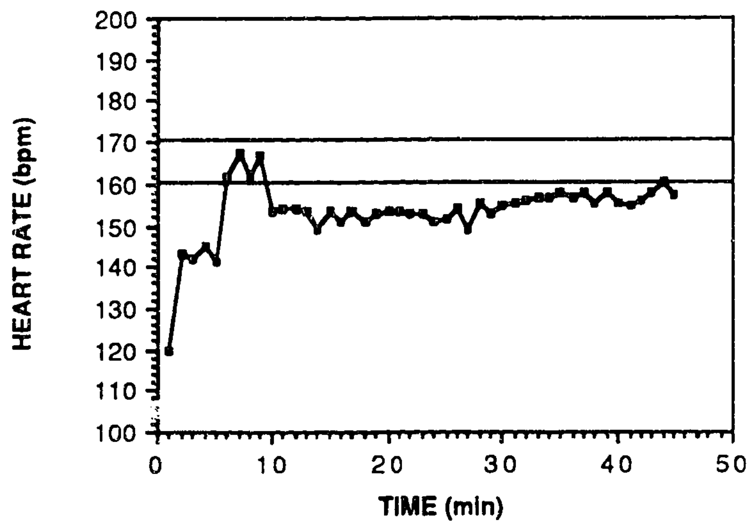
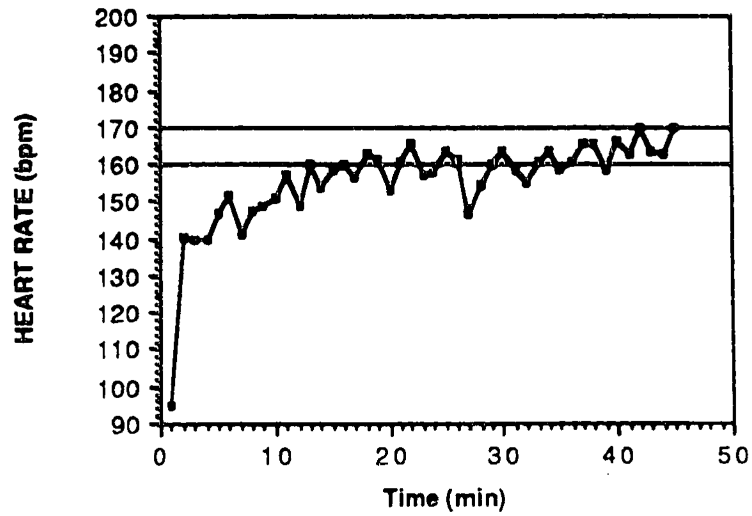


TR RPE-16 heart rate data points of Subject 5.



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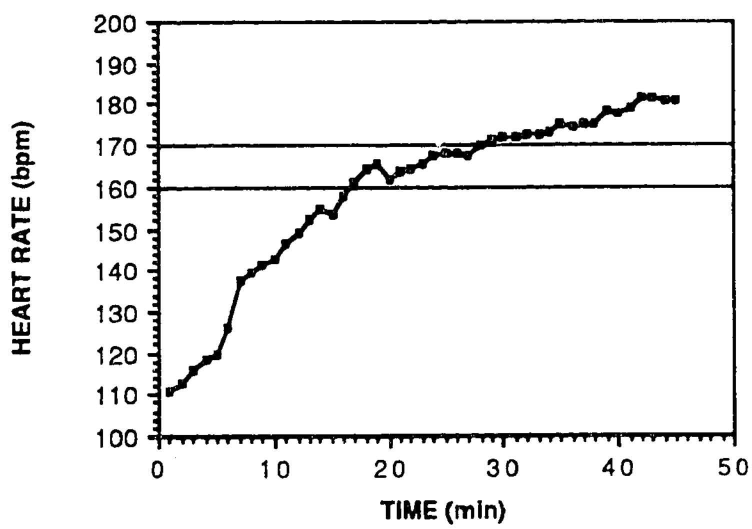

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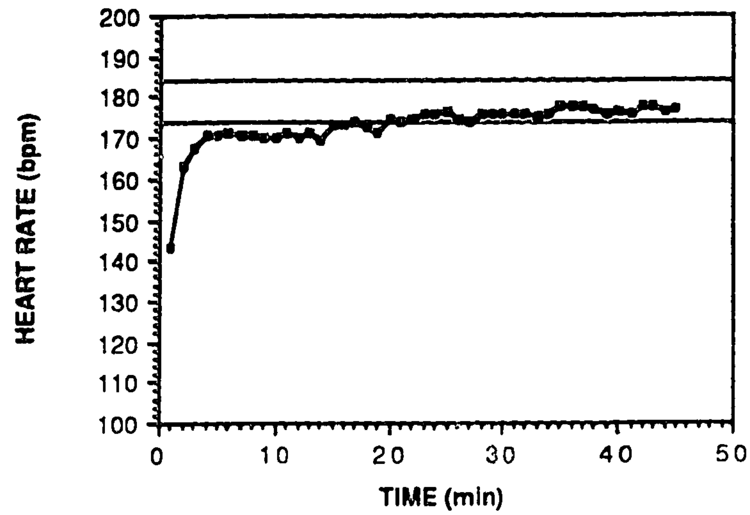

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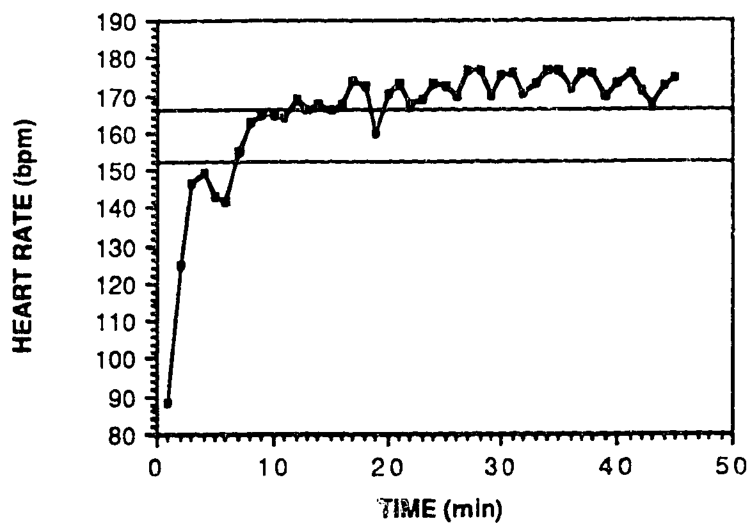

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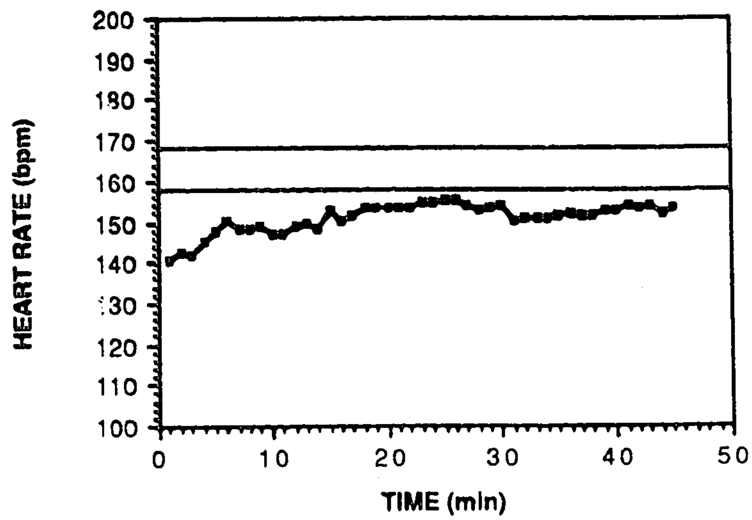

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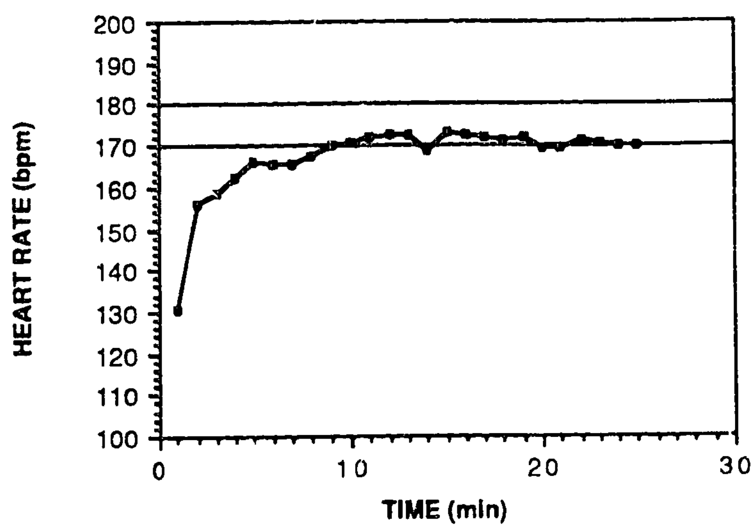

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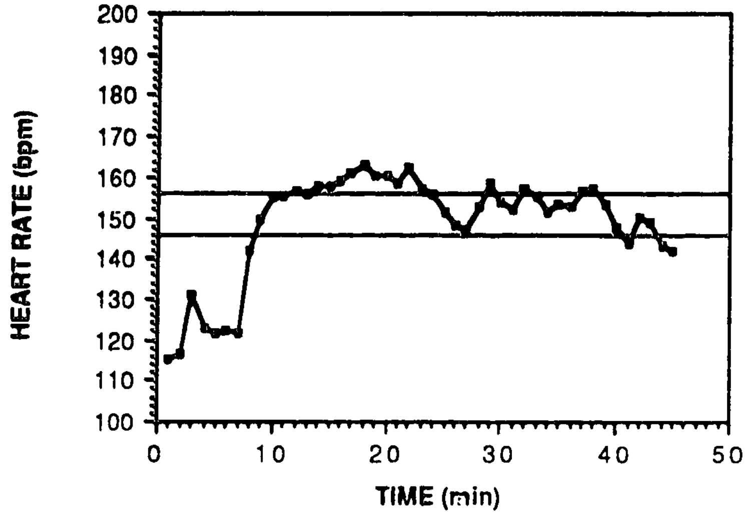

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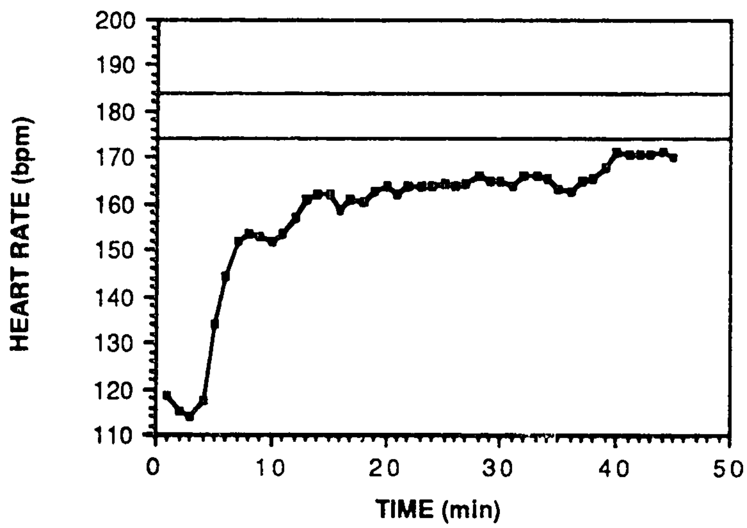

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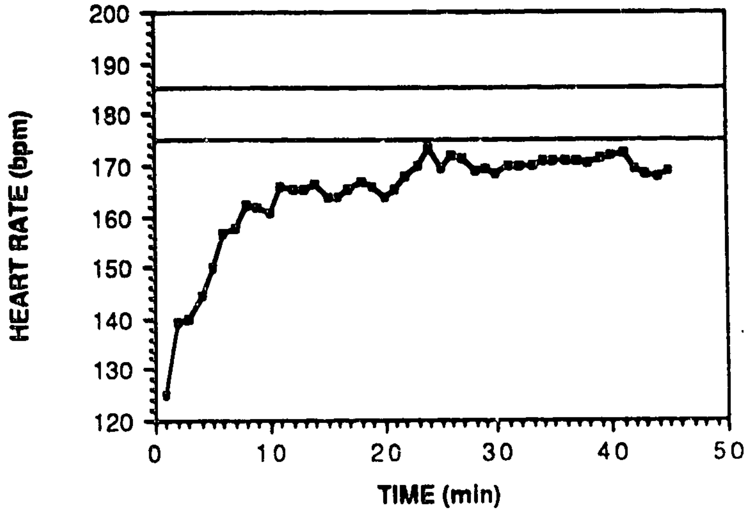

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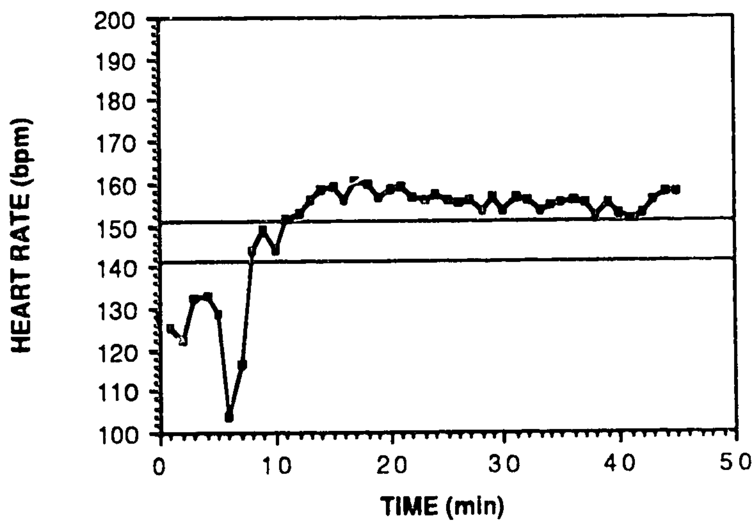

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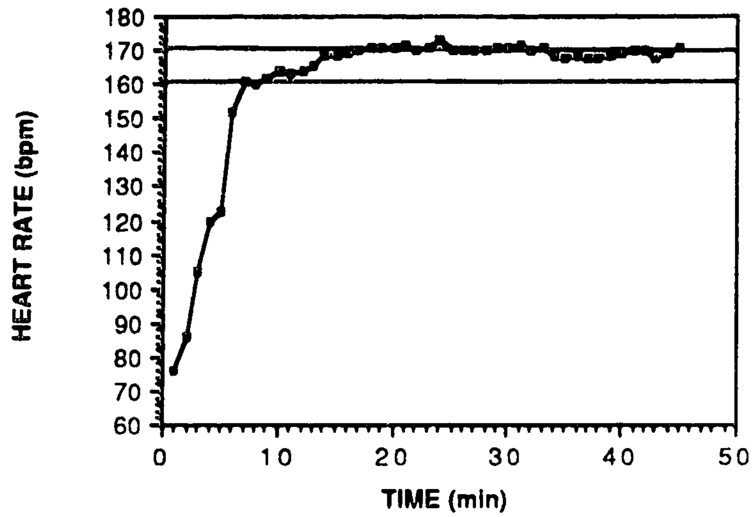

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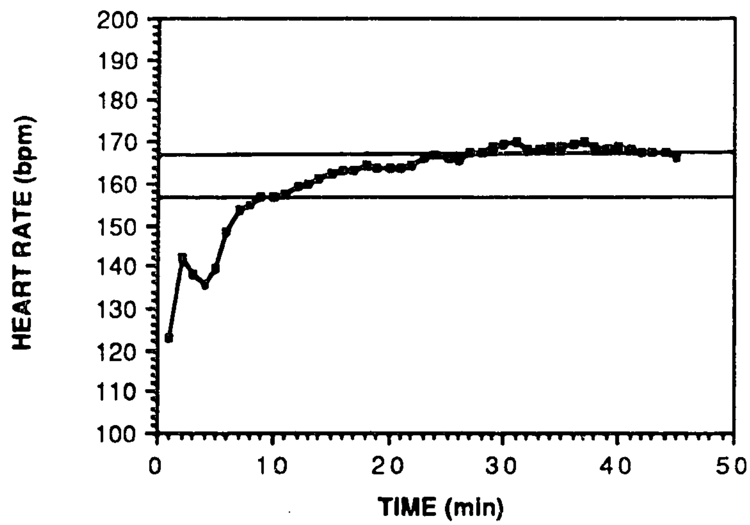

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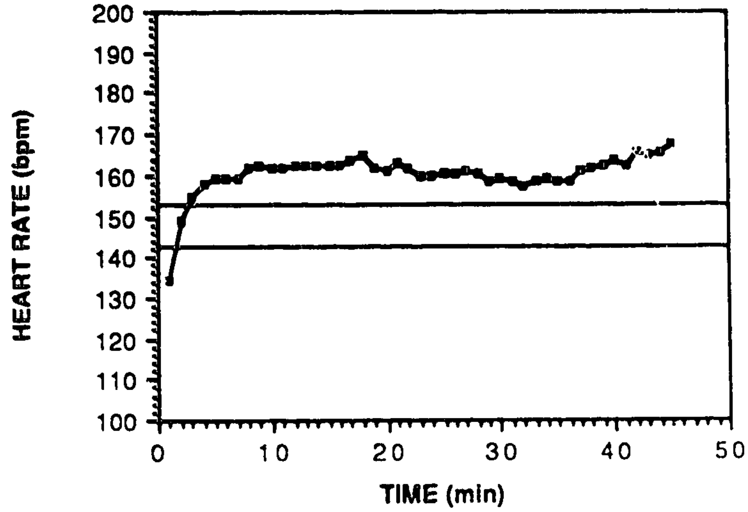

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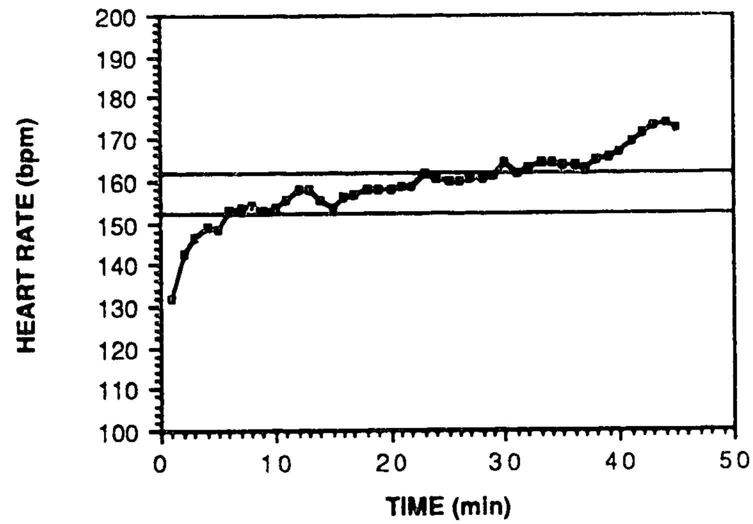

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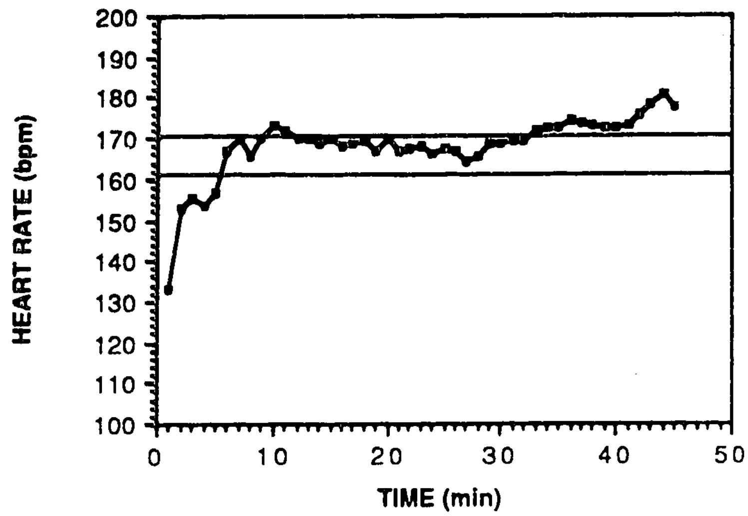

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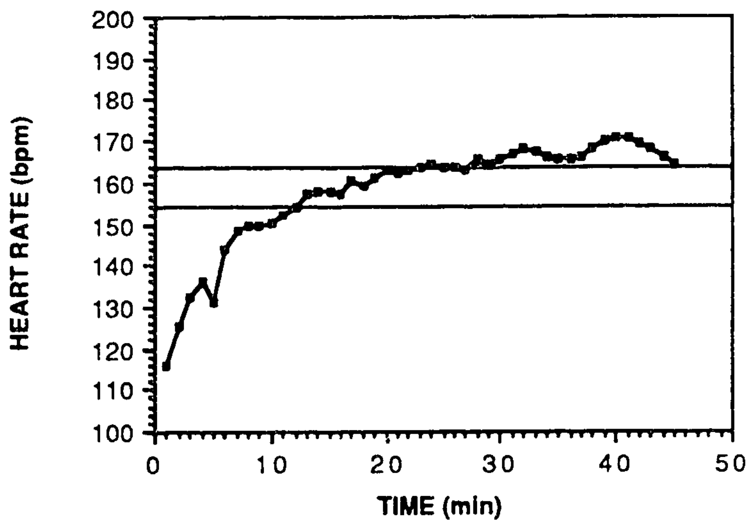
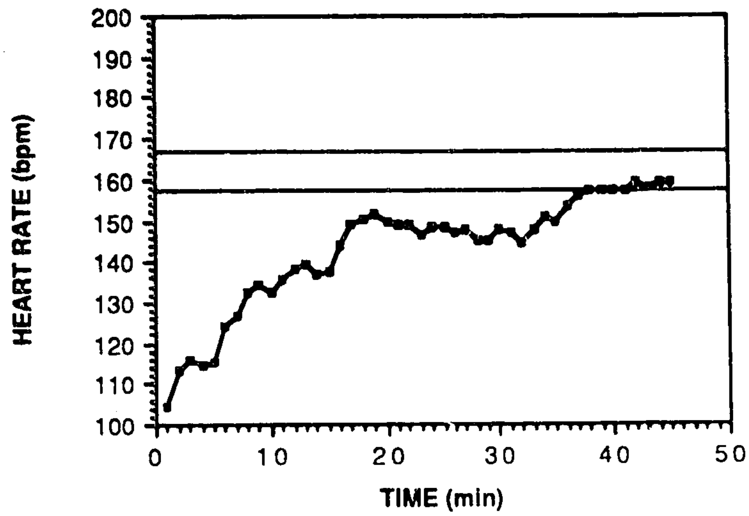


TS RPE-12 heart rate data points of Subject 11.



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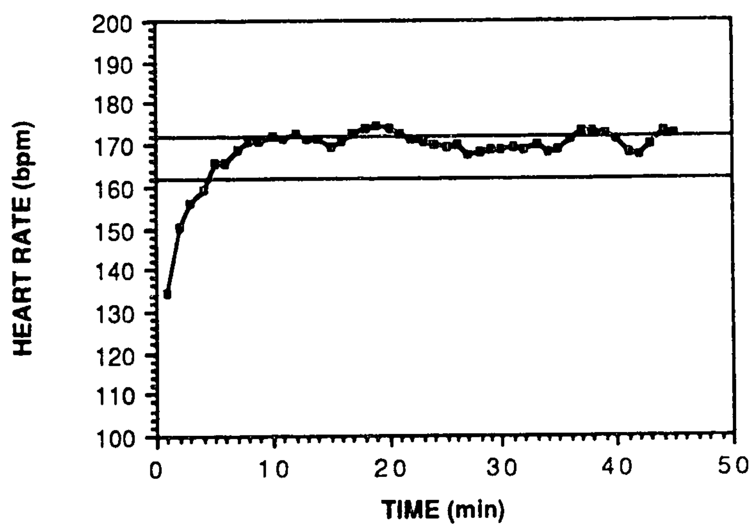

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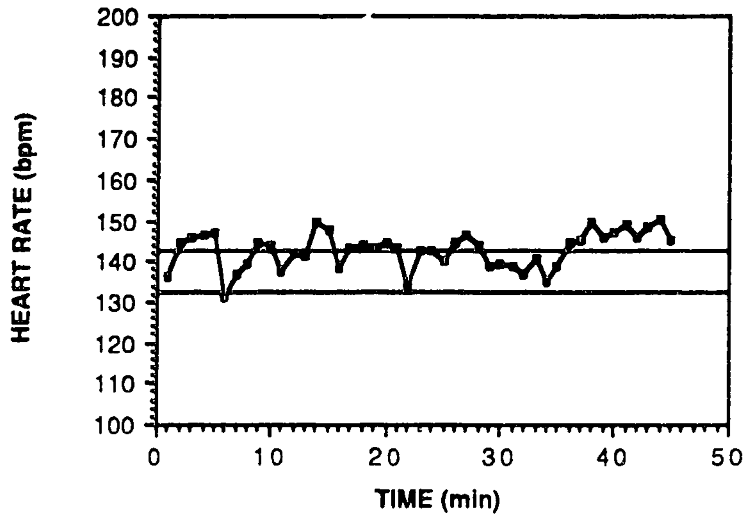

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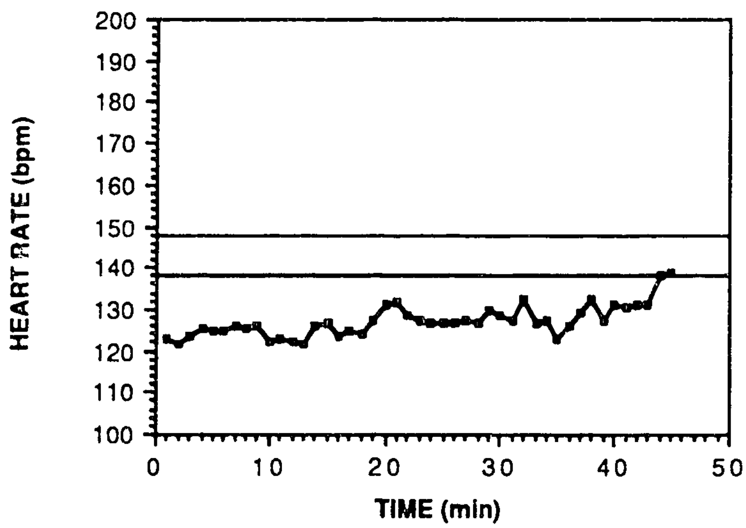

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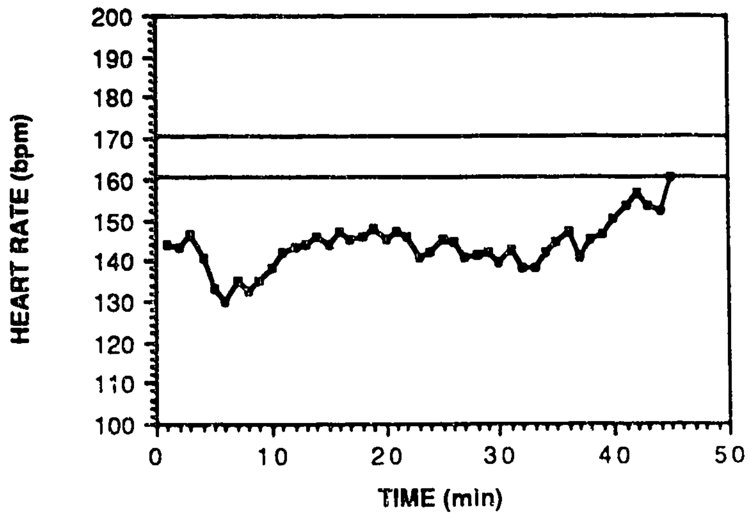

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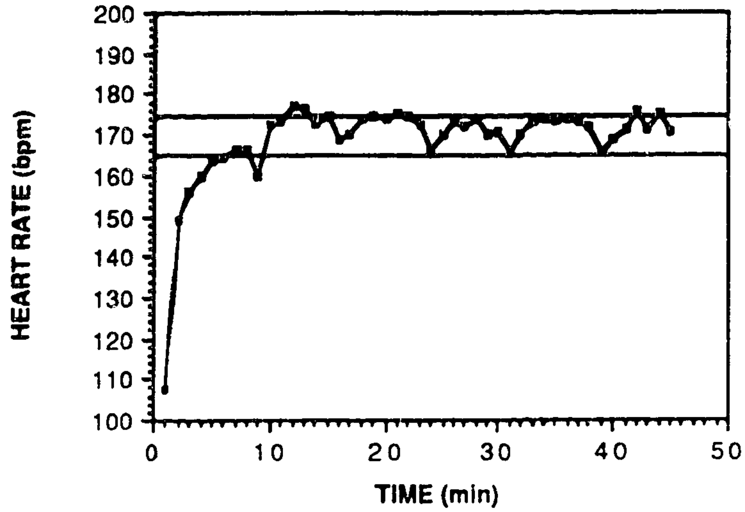

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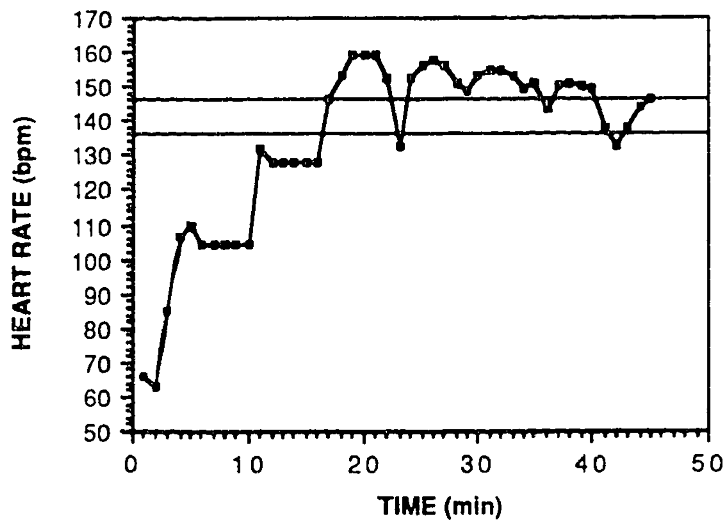

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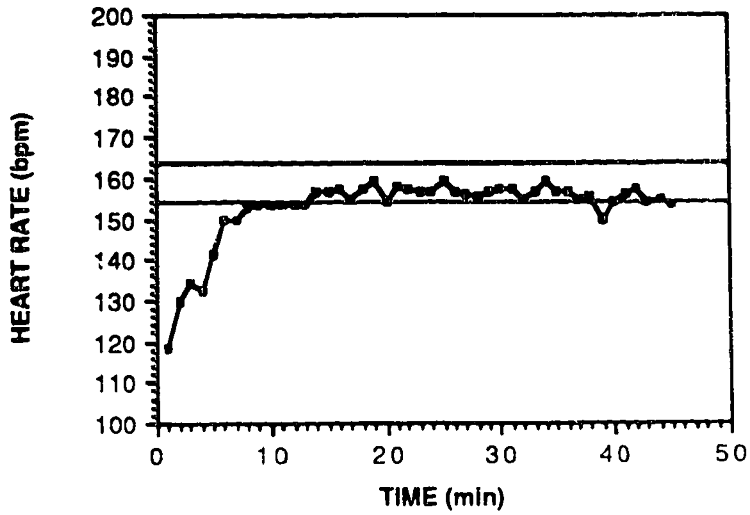

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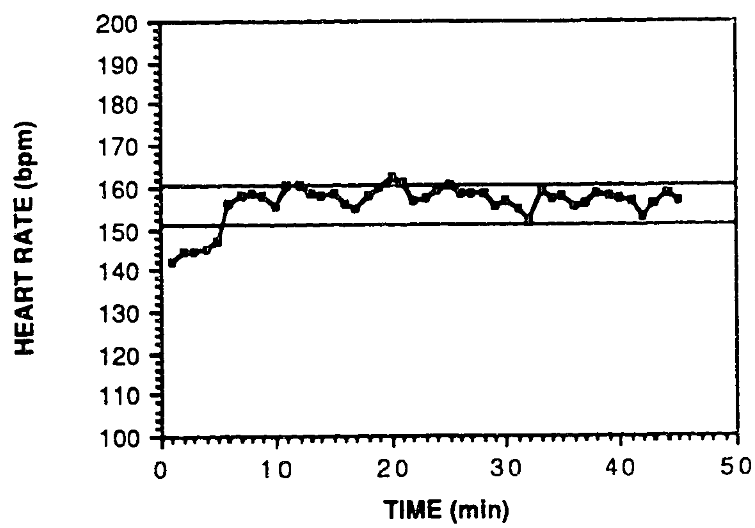

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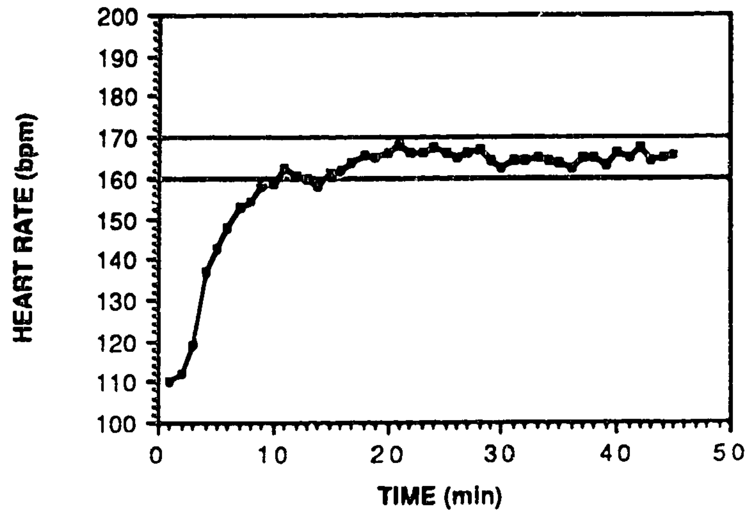

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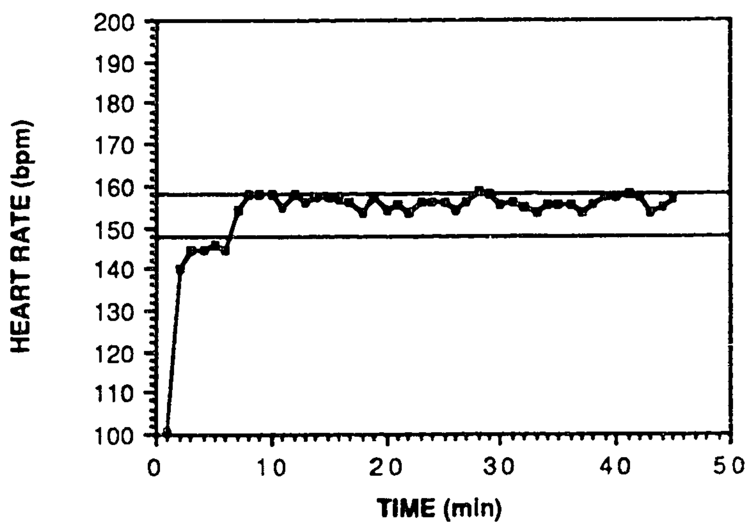

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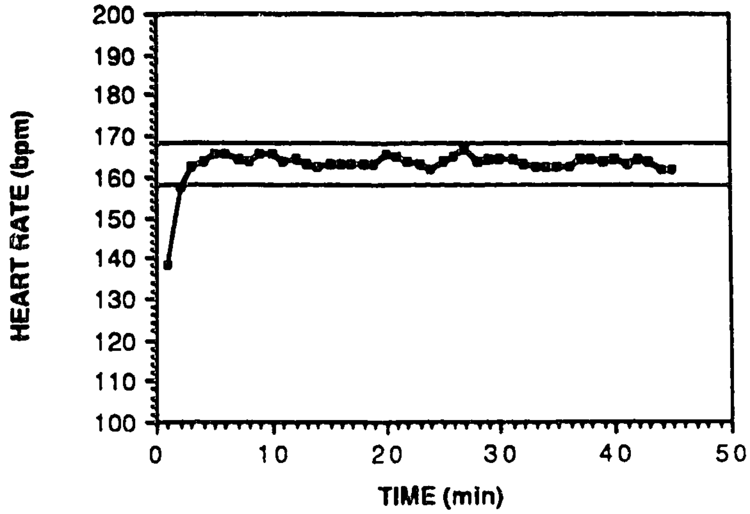

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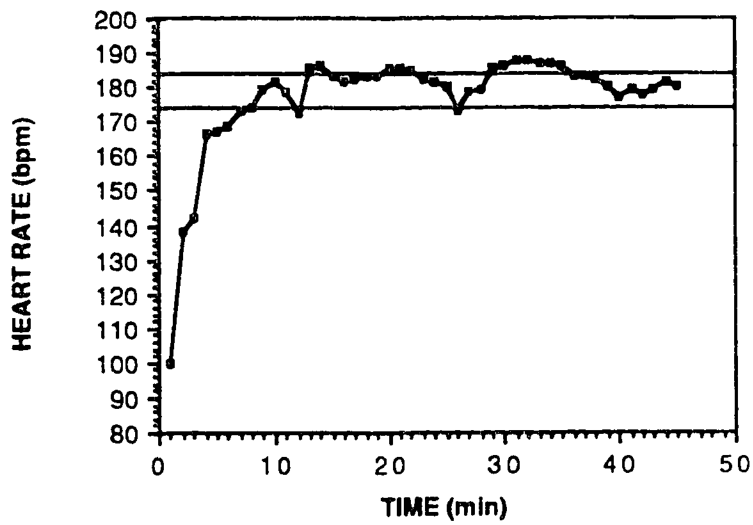

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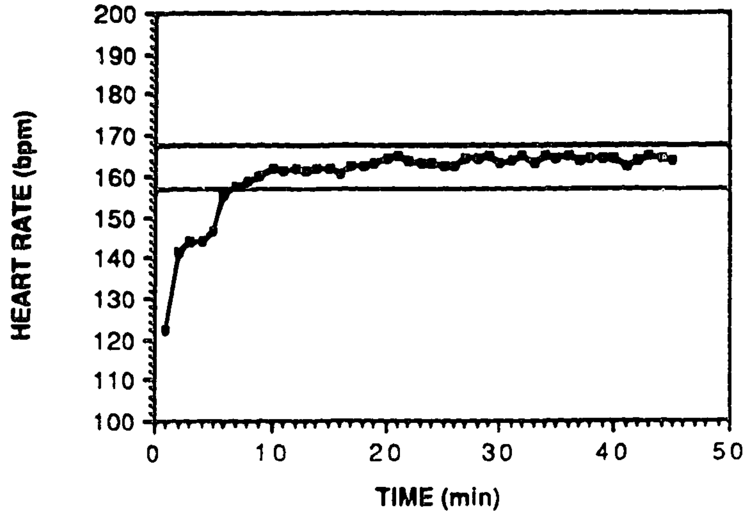

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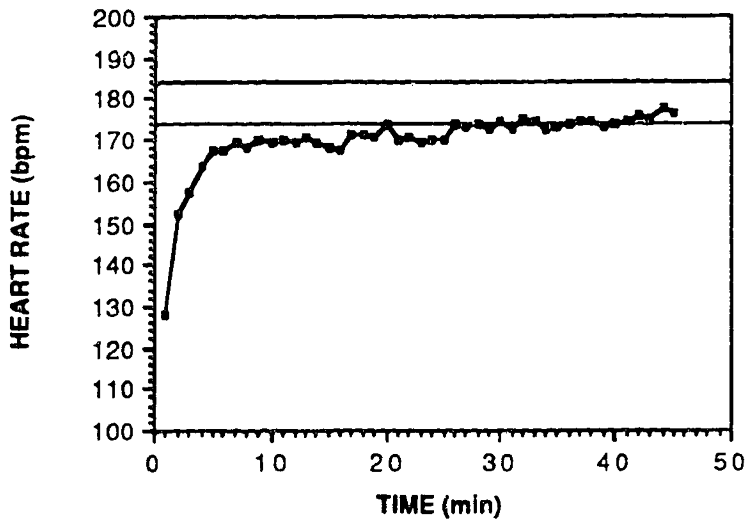

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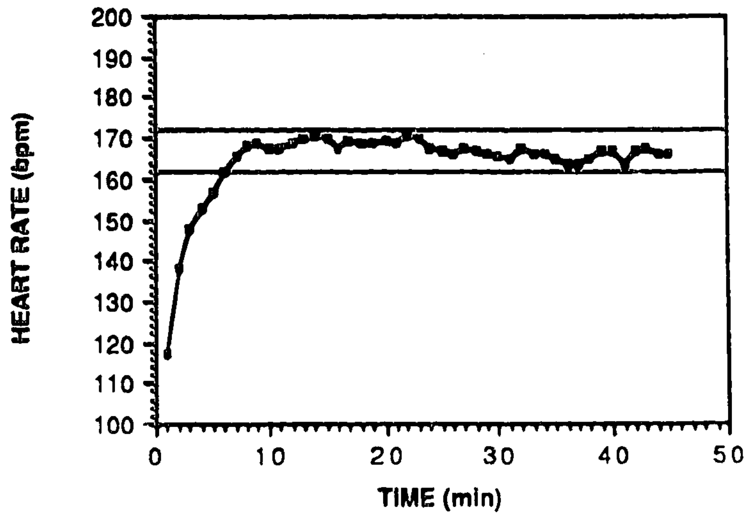

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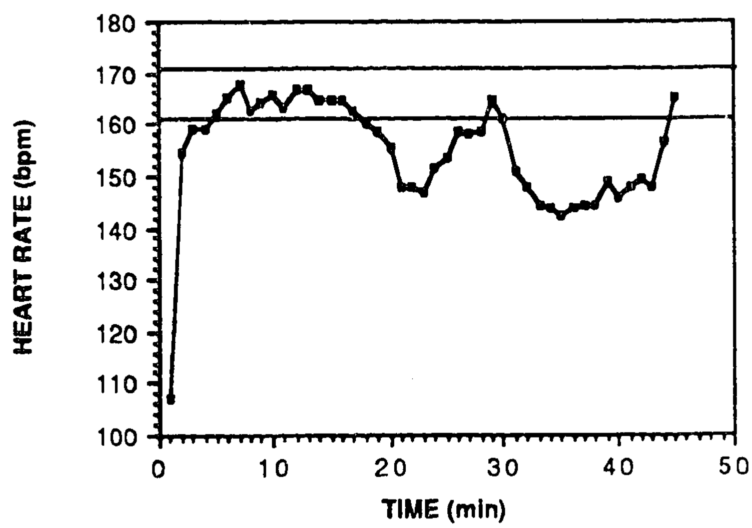

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